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# A Stocktake of Performance Measures in Building and Construction: A systematic review across different countries

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# A Stocktake of Performance Measures in Building and Construction: A systematic review across different countries

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## Abstract

Developing a framework to reliably assess the performance of New Zealand's construction system is an important matter that will require long-term effort. There will need to be a broader range of indicators than have traditionally been used to measure the building system performance, among which productivity would continue to remain a central focus. Given that there is no agreed set of systemic measures across the supply chain, this study is funded by the BRANZ Building Research Levy. It performs a stock take of productivity measures used in building and construction across different countries, within a well-established three-level framework: (1) *industry-level*; (2) *firm-level;* and (3) *project/activity-level*. The discussion focuses on (1) how are these measures constructed and used - *methodology* and *data*; (2) who are using these measures and why - *key users* and *purposes*; (3) the fundamental *assumptions* underpinning these measures; (4) the associated *issues*; and (5) *recommendations* for improving productivity measures at each of these levels.

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# Executive Summary

Developing a framework to reliably assess the performance of New Zealand's construction system is an important matter that will require long-term effort. There will need to be a broader range of indicators than have traditionally been used to measure the building system performance, among which productivity would continue to remain a central focus.

Productivity growth, in general means using less to obtain more. Productivity improvement ensures that valuable resources are being used to their greatest effect in meeting the nation's demand for works related to building and construction. Policymakers and industry practitioners need *'reliable'* industry performance measures to identify better technologies (such as materials and designs) and managerial practices for wider dissemination. Knowledge of these measures is the foundational block upon which the government and industry can develop effective productivity-enhancing policies and strategies, especially when they are being called upon to address questions such as who are being informed by the existing measurements and how; how can we identify highly productive firms among others; and what kind of industry support would promote growth in desirable areas of the business *etc.*

There is however no agreed set of systematic measures across the supply chain, and methods for doing it are far from being fully developed and generally accepted by all interested parties. This study is funded by the BRANZ Building Research Levy, it provides a stock take of productivity measures available in building and construction across different countries.[3]

It has been well established that productivity in construction has multiple meanings, grounded in differing disciplinary perspectives. Previous studies established a three-level framework: (1) *industry-level*; (2) *firm-level;* and (3) *onsite* (i.e. project/activity-level) productivity. The appropriate level at which an evaluation is to be conducted hinges primarily on the purposes of the investigation and the availability of related data.

Industry-level productivity measures are commonly discussed in official reports produced by industry organizations, government agencies and national statistical bureaus. They are macro-economic performance indicators including: (1) partial productivity measures – defined as the ratio between an output and a single input like labour or capital; (2) multi-factor productivity (MFP) measures - the ratio of aggregate outputs relative to an aggregation of labour and capital inputs. Aggregation of outputs and inputs immediately gives rise to index number problems; and (3) KLEMS MFP – KLEMS refers to the five inputs being aggregated: capital (K), labour (L), energy (E), materials (M) and services (S). Through a more detailed statistical decomposition, KLEMS MFP offers more information on the inputs contributing to output growth, which has important implications for building and construction.

[3] Sector *performance* is often used interchangeably with sector *productivity*, but its coverage is broader and extends beyond economic measures of productivity.

We provide three recommendations to improve the industry-level measures. The first is testing an MFP measure based on gross GDP, whereas the existing MFP is derived from real GDP.[4] The second recommendation is developing the KLEMS MFP in New Zealand to separate the distinctive roles associated with energy, materials and services inputs in the construction process. Finally, we could investigate alternative approaches for constructing the measures, to serve differing objectives and situations, an example of this is the Malmquist total factor productivity (TFP) index.

Studies of productivity at the firm-level is less common compared to industry-level. This limited availability can be mainly attributed to the technical research capacities required. There are many venues in New Zealand to add contributions through the utilization of the Longitudinal Business Database (LBD) and the Integrated Data Infrastructure (IDI). We consider it important to fund rigorous firm-level analysis that further break down productivity growth into, the contribution from employing more advanced production technologies (e.g. new ways of building houses), versus the contribution from more efficient application of existing technologies (e.g. eliminating waste under current building technology). For the former, the focus of firm-level analysis is comparing and identifying the best industry practices; for the latter, the related firm-level evaluation concentrates on configuring the determinants of efficient business units. These insights gathered into the frontier building technology would provide policymakers and industry practitioners with more actionable knowledge and an improved lens to understand the drivers of productivity growth, such as what kind of policy initiatives/industrial support would work in practice to enhance productivity, towards what areas and by how much.

The most utilized technique for decomposition of productivity growth at the firm-level is Data Envelopment Analysis (DEA). Another advanced methodology, Stochastic Frontier Analysis (SFA), is a better approach for identifying the characteristics and determinants of efficient construction firms. Simple regression technique, such as the Ordinary Least Squares being adopted by studies currently available in New Zealand, does not have the flexibility offered by the DEA, nor the capability of accounting for random factors as the SFA. We therefore recommend the application of these advanced techniques to evaluate firm performance through the Data Lab service available at Statistics New Zealand.

Finally, at the project/activity level, we look at how the lean concept (waste reduction in particular) have been used in construction and help New Zealand to build better. We recommend: (1) collecting more on-site data across projects of different scales and types; (2) utilizing the information gathered through the Building Information Modelling (BIM); (3) developing a framework to streamline improvements in processes; and (4) ultimately creating a common industry standard to assist construction professionals such as architects, designers, quantity surveyors and project managers *etc.* An example of this is the RSMeans Building Construction Cost Data. The RSMeans Data from Gordian is North America's leading construction cost database. A dynamic collection of data points actively monitored by experienced cost engineers, RSMeans data is used by construction professionals to create budgets, estimate projects, validate their own cost data and plan for ongoing facilities maintenance.

[4] Another long-shot alternative is to replace the GDP based output measure. The building consents administrative data from the local councils might serve as a complementary source.

# 1. Introduction

The construction industry plays a key role in New Zealand (NZ), accounting for 10 per cent of total employment (Rice and Forgan, 2016), and producing approximately 40 percent of all capital formed (Page and Norman, 2014). It is a sector that is closely integrated with the rest of the economy through related services and has a substantive impact on growing and sustaining general economic activity (Rice and Forgan, 2016).

As Best and Meikle (2015, 2019) quoted:

> *Measurement is the first step that leads to control and eventually to improvement. If you cannot measure something, you cannot understand it. If you cannot understand it, you cannot control it. If you cannot control it, you cannot improve it.*
>
> H. James Harrington

Measuring construction in the sense of measuring *quantities of building work* is a well-established technical process carried out routinely by *quantity surveyors*, and in many places, there are agreed-upon rules and procedures that are used for such work. Measuring construction industries or parts of those industries, in the sense of *measuring* things such as *performance and productivity*, is another matter.

Developing a framework to reliably assess the performance of New Zealand's construction system is an important matter that will require long-term effort. There will need to be a broader range of indicators than have traditionally been used to measure the building system performance, among which productivity would continue remain a central focus.

Productivity growth, in general means using less to obtain more. Productivity improvement ensures that valuable resources are being used to their greatest effect in meeting the nation's demand for works related to building and construction. Another way of putting it is that they generate accessible and actionable knowledge helping NZ to build more at a lower cost. Policymakers and industry practitioners need reliable performance measures to identify better technologies (such as materials and designs) and managerial practices for wider dissemination. Knowledge of these measures is the foundational block upon which the government and industry can develop effective productivity-enhancing policies and strategies, especially when they are being called upon to address questions such as who are being informed by the existing measurements and how; how can we identify highly productive firms among others; and what kind of industry support would promote growth in desirable areas of the business *etc.*

There is however no agreed set of systemic measures across the supply chain, and methods for doing it are far from being fully developed and generally accepted by all interested parties. This is not only an issue in building and construction but a broader issue on the national policy watch.

This study is funded by the BRANZ Building Research Levy, it provides a systematic stock take of the performance measures relating specifically to sector productivity. Although *sector performance* is often used interchangeably with *sector productivity*, we should be aware of that its coverage extends beyond *economic measures of productivity*. The purpose of this study is developing a better understanding of measures related to productivity for achieving sustained growth.

Existing evidence suggests that in New Zealand, measuring the performance of the construction sector is mostly reliant on *macro-economic data* and the general conclusion is that *productivity growth has been stagnating*. This is well documented in a comprehensive series of reports published by BRANZ (Page, 2010; Page and Curtis, 2011, 2012; Page, 2013a, 2013b; Norman *et al.* 2014; Page and Norman, 2014; Curtis, 2017; Curtis, 2018) among others (Rice and Forgan, 2016; Tran, 2010). Nonetheless, the assessments may not be fair due to the pitfalls associated with *aggregate measures at the industry-level*, including the lack of appropriate quality adjustment and the failure to differentiate heterogeneous units. To illustrate, labour input is measured by employee counts or hours paid; it does not distinguish a day's work carried out by a master builder from a day's work carried out by an apprentice. Output is typically measured by industry real GDP (i.e. value-added) or the value of building consents issued; they do not account for different types of buildings – a stand-alone dwelling versus an apartment. Using the Longitudinal Business Database (LBD), studies *disaggregated at the firm-level* (Jaffe *et al.* 2016; Jaffe and Chappell, 2018) reveal the opposite, *productivity* has been found to *accelerate* (instead of deteriorating) *since 2001*, and the speed of improvement has outperformed businesses in other comparison sectors.

Furthermore, comparative studies across different countries suggest that: (1) total factor productivity for construction in NZ has grown at only half the rate of the UK (Page, 2010), and (2) labour productivity for construction in NZ has grown at only half the pace of Australia (Eaqub, 2013). This relative performance comparison is normally carried out to identify shortcomings in one place and then to look for ways to deal with them. However, without adequate understanding and acknowledgements regarding the comparability issues involved, it is unclear to what extent these studies could be utilized for national productivity evaluations and policy prescriptions.

It has been well established that productivity in construction has multiple meanings, grounded in differing disciplinary perspectives. In an earlier report commissioned by the NZ Department of Building and Housing, Davis (2007) provides a three-level framework to assess productivity: (1) *industry-level* productivity; (2) *firm-level* productivity; and (3) *onsite* (i.e. project/activity-level) productivity. Each level is presented from a different perspective described by a corresponding set of input-output measures. Jaffe *et al.* (2016) also categorized international research on construction productivity into these three strands. Abbott and Carson (2012) summarized measures of labour productivity for construction in NZ, whereas Yi and Chan (2014) provide a more critical international assessment (i.e. broader scope) of the same, which covers 135 papers published in 10 journals of construction management and economics.

The appropriate level at which an analysis is to be conducted depends primarily on the purposes of the investigation and the availability of related data. Research organizations (such as BRANZ in NZ and ECITB in the UK) and government agencies (e.g. Productivity Commissions, Treasuries, MBIE, statistical and economic research Bureaus) often carry out analysis at the aggregate industry-level. The purpose is to introduce policies and industry strategies that promote industry growth. Firm-level analysis serves similar purpose with better understanding towards the building technologies involved and therefore the knowledge produced for decision makers at the higher level is more fruitful and actionable. Project or activity level analysis is more common when the subject matter under investigation is the impact of specific design, procurement strategy or on-site management tool. A lower level of aggregation (i.e. a higher level of disaggregation) enables better identification of the sources of productivity growth and control for heterogeneity in outputs; the associated research costs however are more substantial. This study evaluates productivity measures at each of the assessment levels across different countries. The discussion focuses on (1) how are these measures constructed and used - *methodology and data*; (2) *who* are using these measures and *why* - *key users and purposes*; (3) the *fundamental assumptions* underpinning these measures; (4) the associated *issues*; and (5) *recommendations* for improving productivity measures at each of these levels.

## 2. Industry-level Performance Measures

Industry-level productivity index measures are most commonly evaluated by research organizations and government agencies including national statistical bureaus because: (1) they are based on aggregate macro-economic data available in national accounts; (2) they are perceived to be the first stop for policymakers and industry practitioners to design policies and evaluate the state of the sector; and (3) the latter is often performed by direct comparison with the rest of the economy (i.e. *inter-industry* comparison).

For instance, a list of policy recommendations based on industry-level analysis has been provided by Rice and Forgan (2016), including the change of traditional public procurement approaches to reduce industrial fragmentation; incentivize innovation across the value chain, and plan the timing of government investment to help smooth the boom-bust cycle. These recommendations are high level strategies with relevance extending beyond the context of performance measuring.

We provide a critical examination of key industry-level productivity measures in ***Table 1***. They are the conventional measures employed by government agencies across the world. We can categorize these macro-economic performance indicators into: (1) partial productivity measures – defined as the ratio between output and a single input like labour or capital; (2) multi-factor productivity (MFP) measures - the ratio of aggregate outputs relative to an aggregation of labour and capital inputs. Aggregation of outputs and inputs immediately gives rise to index number problems; and (3) KLEMS MFP – KLEMS refers to the five inputs being aggregated: capital (K), labour (L), energy (E), materials (M) and services (S). Through a more detailed statistical decomposition, KLEMS MFP offers more information on the inputs contributing to output growth, which has important implications for building and construction.

The following discussion will examine at length each of the categories, being extracted mostly from the various information papers published by the *Australian Bureau of Statistics* (*ABS*). The OECD put together several handbooks and manuals to set out a guide for best practice in productivity measurement, the *ABS* is an active contributor on this front and produces works of high quality. On top of this, our geographical proximity and socio-economic similarity also indicate *Statistics NZ* could look to *ABS* as an example of what improvements should be made to national accounts and related productivity measures.

## Table 1 – Summary of Key Industry-Level Performance Measures

| Productivity Measures (Industry Level) | Key Users | Purposes | Methodologies and Data | Assumptions | Key Issues | Recommendations |
|---|---|---|---|---|---|---|
| **Labor Productivity** | ***Government Agencies:***<br>***Treasury, MBIE (Building and Energy), Productivity Commission, Statistics New Zealand, Ministry of Housing and Urban Development, Housing New Zealand.***<br><br>***Industry Practitioners:***<br>***BRANZ, Construction Sector Accord, Construction Industry Council.***<br><br>They are common macro-economic performance indicators ***routinely published by National Statistical Bureaus*** in NZ, Australia, and other OECD countries. The OECD has produced a number of handbooks and manuals to set out a guide for best practice in productivity measurement. | These partial productivity measures are perceived to be the first stop for policy makers and industry practitioners to ***design policies and evaluate the state of the sector***. More specifically, they are<br>(1) usually expressed in terms of ***growth rate***;<br>(2) widely used for making ***historical, inter-industry and inter-country growth comparisons***;<br>(3) often regarded as ***an indicator of improvements in living standards*** as growth in labor productivity has close long term relationship with growth in labor earnings;<br>(4) ***has a close relationship to MFP*** . In the growth accounting framework, ***growth in labor productivity can be decomposed into growth in capital deepening, growth in labor quality and growth in MFP*** . | **Output measures:**<br>• Gross GDP Index in Construction (***gross output measure***)<br>• Real GDP Index in Construction (***chain volume value-added measure***)<br>• Value of fixed capital formation for building and civil structures<br>• Total value of building consents/residential consents<br>• Total floor areas of building consents/residential consents<br><br>**Input measures:**<br>• ***Labor units (hours paid )*** index and ***Capital units*** index.<br>• Employment count.<br>• FTE count.<br><br>These measures are based on industry-level ***official statistics***. Available through *Infoshare*. These official statistics are constructed by Statistics NZ using a combination of household survey data, establishment survey data, census data and linked employer-employee data (LEED).<br><br>The measurement of ***capital input*** is concerned with estimating the contribution of capital to the production process; that is, ***the flow of capital services from the capital stock*** used in the production process. The productive capital stock are estimated from data of gross fixed capital formation (except inventories and land), using the ***Perpetual Inventory Method (PIM)*** - weighted chain volume measures, the rental prices can be regarded as the 'wages' of capital and used as the weights. Capital rental price consists of three components: the rate of return to capital, the depreciation rate and the capital gain or loss due to revaluation. ***The essence of this method is to transform all capital assets of different vintages into equivalent efficiency units and then add them up into an estimate of the productive capital stock.*** | (1) Output Measure - ***The value added concept is developed to facilitate the comparison of productivity across different industries.*** This definition is based on the ***assumption that the components of value added are separate from that of intermediate inputs***. The assumption also implies a *specific way that productivity growth affects the usages of primary and intermediate inputs;*<br><br>(2) Input Measure - the quantity of "capital services" is estimated by assuming that capital services produced by an asset are proportional to the value of productive capital stock. ***The capital utilization rate is assumed to be constant over time;***<br><br>(3) The approach taken for estimating MFP is based on the ***neoclassical theory using a translog production function*** in conjunction with two assumptions: ***constant returns to scale***; and that the marginal products of capital and labor are equal to their respective real market prices (i.e. ***perfect competition in factor markets***). However, these assumptions are unlikely to hold in practice. If there are scale efficiencies then this will also be captured as an increase in MFP. This might be more of an issue for the NZ construction sector as many small firms are operating in an environment of increasing returns to scale, especially over short periods. | (1) ***Inter-country*** comparisons are difficult and unreliable due to factors influencing productivity between countries, including the mix of work types, firm sizes, the size of the black economy (unregistered workers), and what stages of the business cycle is measured;<br><br>(2) ***Inter- industry*** comparison issues - the value added approach in measuring output implies a specific way that productivity growth affects the usage of primary and intermediate inputs, which might not be applicable to construction. The actual industry coverage for building and construction is boarder than being defined by the "ANZSIC06 classification Division E". Much of the efficiency gains (e.g. pre-fabrication) in construction may be captured by other industries such as Manufacturing (of construction materials) - Division C; Rental, Hiring and Real Estate Services - Division L; and Professional, Scientific and Technical Services - Division M etc.<br><br>(3) The indexes of hours worked (not paid) or ***quality adjusted hours worked*** are preferred measure of labor input but currently unavailable in NZ at the moment;<br><br>(4) In the short to medium term, MFP estimates are subject to variations in capacity utilization or other factors such as weather;<br><br>(5) ***MFP*** estimates are probably most useful when viewed as ***average growth rates between growth-cycle peaks***, which are determined as peak deviations of the market sector MFP index from its long-term trend. In this way, most of the effects of variations in capacity utilization and much of the random error are removed. | (1) Due to the assumptions involved in the construction of the value-added MFP index, and the nature of the industry (i.e. dynamics between primary factor inputs and intermediate inputs), we ***do not recommend making direct comparisons across different industries***;<br><br>(2) ***Acknowledge data compatibility*** issue when making comparisons ***across countries***;<br><br>(3) The ***gross output based MFP***, instead of the value-added output based MFP, ***should be tested as an alternative***. Gross output is a natural output concept and consistent with the traditional production theory which links output to primary as well as intermediate inputs (i.e. a better reflect of the production process);<br><br>(4) ***Experiment with KLEMS MFP using the supply-use table complied by StatsNZ***;<br><br>(5) Explore the LBD and IDI (StatsNZ integrated administrative datasets) for alternative measures of output (e.g. building consents data) and input (e.g. tertiary education dataset) to ***account for quality changes***;<br><br>(6) ***Explore alternative approaches*** (e.g. the Malmquist total factor productivity index or the component-based approach) for measuring productivity change in order to better identify drivers of productivity growth. |
| **Capital Productivity** | | Changes in this ratio can ***reflect technological changes***, and ***changes in other factor inputs*** (such as labor). | | | | |
| **Capital Intensity (Capital Deepening)** | These partial productivity measures are ***the most commonly discussed performance indicators*** for NZ building and construction. This is primarily because they are aggregate macro-economic indicators ***readily available through Infoshare*** (an online tool that gives free access to a range of time-series data published by StatsNZ). | Increased capital deepening means that, on average, each unit of labor has more capital to work with to produce output, so is ***an indicator of ability to augment labor***.<br><br>Labor saving practices, such as automation of production, will result in increased capital deepening, which is often associated with a decline in capital productivity. Thus growth in capital deepening is an ***important driver (alongside MFP) of labor productivity growth*** . | | | | |
| **Multi Factor Productivity (MFP)** | ***MFP measures the difference between the growth in the volume of 'aggregated' output and the growth in the volume of 'aggregated' inputs***, reflecting more than just technical progress including: economies of scale; reallocation of inputs; changes in human capital; variations in capacity utilization; climate events; and measurement error. Year-to-year changes also contain 'noise' that is distinct from the notion of technical progress. | (1) ***At the aggregate level*** , MFP is defined as the ratio of ***real value added*** to the combined inputs of capital and labor;<br>(2) ***Within an industry*** , MFP is also measured as the ratio of ***gross output*** to the combined inputs of capital, labor, and ***intermediate inputs;***<br>(3) Economic statistics fit for one purpose may not be fit for others; ***MFP measures are developed for conducting analysis of long term productivity growth. It is not ideal for users to employ them for assessing short term productivity fluctuations.*** | | | | |
| **KLEMS MFP** | Published by National Statistical Agencies across the world such as Australia, the EU, USA, Canada, Japan, Korea, India, China, Brazil and Argentina.<br><br>***KLEMS refers to the five inputs considered in the construction of MFP*** , which include ***capital (K), labor (L), energy (E), materials (M) and services (S)***.<br><br>A gross output measure (instead of the value-added measure) is used. Separately identifying energy, materials and services is beneficial as ***each of the inputs have distinctly different roles in the production process***. | KLEMS is a useful tool in addressing the challenge of developing ***more detailed industry performance indicators*** for the ***formulation and evaluation of policies involving long-term growth, efficiency and competitiveness.***<br><br>***It provides*** through a more detailed statistical decomposition, ***better information on the inputs contributing to output growth and production efficiency***.<br><br>This helps policy makers and economists to ***identify factors associated with economic growth such as structural changes in industry's input mix*** , particularly with regards to the ***relative contribution from intermediate inputs***. The classification of intermediate inputs into energy (E), materials(M) and services (S) is beneficial in that they have distinctively different roles in building and c construction. ***This helps in evaluating trends in the way industries interact*** . | **Intermediate inputs measures:**<br>• energy units index<br>• materials units index<br>• services units index<br><br>Australia:<br>The intermediate inputs indices and their respective shares are sourced from the ***supply-use tables (SUT)*** complied by the Australian Bureau of Statistics. The main advantage of deriving the indices and shares using this method is to ***control for heterogeneity in both the prices and volumes of the components*** and to ***recognize more explicitly that the way in which each*** of these components ***contributes to production*** differs. A key development in the SUT has been the wider application of the double deflation method, that is, ***real output and real intermediate inputs are derived separately for most industries***. By sourcing specific price deflators, ***the approach enables improved volume estimation*** , particularly for intermediate inputs. | | | |

## 2.1 Partial productivity measures

StatsNZ routinely publishes official indexes of labour productivity, capital productivity and multifactor productivity (MFP) across different industries under the *Economic Indicators* on *Infoshare*.[5] Productivity is typically measured as output per unit of input. Partial measures of productivity take into consideration a single input like labour or capital.

### 2.1.1 Labour productivity

Labour productivity is the most commonly discussed indicator of productivity growth, it has been widely used for making *historical*, *inter-industry* and *inter-country* growth comparisons:

$$Labour\ Productivity\ Index = \frac{Real\ GDP\ Index\ in\ Construction}{Labour\ Input\ Index\ in\ Construction}$$

Labour productivity growth is often regarded as *an indicator of improvements in living standards* as growth in labour productivity has a close, long term relationship with growth in labour earnings. Labour productivity also has a close connection to multifactor productivity (MFP).

Several Treasury working papers, and research reports released by the Productivity Commission, examined these official productivity indexes (Black *et al.* 2003; Fox, 2005, Mason and Osborne, 2007; Conway and Meehan, 2013; Conway, 2016; Nolan *et al.* 2019). They performed analyses for the overall economy aggregated at the national level, but separate evaluations for each industry sector (including building and construction) were provided in these reports. Meanwhile, BRANZ published a series of construction productivity studies (Page, 2010; Page and Curtis, 2011, 2012; Page, 2013a, 2013b; Norman *et al.* 2014; Page and Norman, 2014; Curtis, 2017; Curtis, 2018; Rice and Forgan, 2016; and Eaqub, 2013), the majority of which relied on official industry-level productivity indexes.

The partial labour productivity is the ratio between output and labour input, the most straightforward measure of labour input is a ***count of the labour force***. This is usually the easiest to obtain, but workers are given the same weight regardless of whether they work full-time or part- time. A measure of the ***full-time equivalent (FTE) labour force*** is preferred to a straight count as it assumes that a part-time worker weights one-half that of a full-time worker.

An improvement to the FTE volume is a measure of ***hours paid***. Often workers are paid for a set number of hours, but it is common for workers to change the number of hours from week to week. ***Hours worked*** is a more accurate measure of labour volume than hours paid. Nonetheless, it implicitly assumes that the workforce is homogeneous, does not recognise improvements to human capital due to the varying educational achievements and experience within the workforce.

[5] *Infoshare* is a free-of-charge online tool that gives access to a range of time-series data published by StatsNZ such as economic information, population demographics, wholesale and retail trade information, exports and imports data, and building consents data *etc.*

As a result, the most representative measure of labour volume is ***composition-adjusted hours worked*** (often referred to as ***quality-adjusted labour input*** - QALI in Australia), which gives more weight to units of relatively higher skill. In this way, *increases in labour input can be divided between total hours worked and compositional changes in the labour force*. As the workforce evolves with more educated workers replacing less educated workers, this compositional change can directly affect how much output can be produced from a given quantity of hours worked. The labour compositional change combined with labour share has become a standard method for quantifying the contribution of human capital to economic growth within the modern growth accounting framework.[6]

Unfortunately, only ***unadjusted hours paid*** is available in the Quarterly Employment Survey (QES)
being utilized to construct labour input. StatsNZ acknowledges that options for modelling ***hours worked*** are available from the Household Labour Force Survey (HLFS). However, there are concerns about the robustness of HLFS industry totals and insufficient understanding of factors affecting quarterly industry movement. More work is required to investigate possible auxiliary data sources that can be used for modelling actual hours worked. A comprehensive range of labour demographics (e.g. sex, age and residence) in the Integrated Data Infrastructure (IDI) could be explored for this purpose. For instance, the information on education alone is attainable from the census and the tertiary education dataset in IDI.

Of specific interest to economists are the underlying causes of economic growth. Typically, partial indexes are not sufficient for this purpose. Labour productivity indexes reflect not only the contribution of labour to changes in production per labour unit but are also influenced by the contribution of capital and other factors affecting production such as technological change. In the modern growth accounting framework, growth in labour productivity can be decomposed into growth in capital deepening (worker is equipped with more capital), growth in labour quality (worker is equipped with more knowledge) and growth in multifactor productivity.

### 2.1.2 Capital productivity

Capital productivity is another frequently discussed partial measure alongside labour productivity, and changes in this ratio also reflect technological changes and changes in other factor inputs:

$$Capital\ Productivity\ Index = \frac{Real\ GDP\ Index}{Capital\ Input\ Index}$$

[6] Incomes per capita have grown dramatically over the past two centuries, but the increase has been unevenly spread across time and across the world. ***Growth accounting*** is the principal quantitative tool for understanding this phenomenon, and for assessing the prospects for further increases in living standards. It grew out of the convergence of national income accounting and growth theory, and, in its simplest national income form, it is a rather straightforward exercise in which the growth rate of real GDP per capita is decomposed into separate capital formation and productivity effects. The unevenness of growth rates over time and across countries can then be traced to these two general sources, providing insights into the nature of the growth process. This is the simple story of growth analysis. A more complex tale has emerged over time as data and computing power have improved, and economic theory has evolved. In the process, growth accounting has itself changed, and one can refer to Hulten (2009) for a discussion of this evolution.

StatsNZ measures capital input with the ***flow of capital services*** coming from the capital stock, and
most capital assets are derived from *gross fixed capital formation* using the perpetual inventory method (PIM) consistent with international best practice. Capital services have both quantity and price dimensions. The quantity of capital services represents hours a machine is used or months a building is occupied. The price dimension, called the rental price, represents an hourly rate for using machines or a monthly rate for occupying premises. Capital rental price consists of three components: the rate of return to capital, the depreciation rate and the capital gain or loss due to revaluation.

The quantity of capital services is estimated by assuming that capital services produced by an asset are proportional to the value of the productive capital stock (i.e. constant capacity utilisation rate), and as a consequence, changes in the capital services over time may reflect the impact of short-term business cycles, other than movements of capital input.

It is common for capital to be rented under an operational lease arrangement from a firm primarily operating in another industry. For instance, a construction company may lease a crane from the rental and hiring industry, which is recorded as a service component in the intermediate inputs of the lessee and as capital services held by the lessor. A reduction in the percentage of capital held within an industry over time, such as when a firm lease rather than purchases capital, would understate growth in the capital service index, which would affect the value-added MFP growth too. More discussion of this is provided in the KLEMS MFP section (2.3).

### 2.1.3 Capital deepening

Capital deepening (or capital intensity) refers to changes in the capital to labour ratio:

$$Capital\ Deepening\ Index\ = \frac{Labour\ Input\ Index}{Capital\ Input\ Index}$$

Increased capital deepening means that, on average, each unit of labour has more capital to work with to produce output, so is an indicator of ability to augment labour. Labour-saving practices, such as automation of production, will result in increased capital deepening, which is often associated with a decline in capital productivity. Thus, growth in capital deepening is a vital driver (alongside MFP) of labour productivity growth. It is not recommended to interpret declines in capital productivity in isolation since they can be more than offset by labour productivity (resulting in MFP growth).

## 2.2 Multi-factor productivity (MFP)

Relative to partial productivity measures, MFP offers more explanations to the sources of productivity growth. They are designed to inform how much economic growth originates from productivity growth (increased outputs from the same quantity of inputs) and how much from increased inputs (increased outputs from more capital goods or additional working hours):

$$MFP\ Index = \frac{Real\ GDP\ Index}{Weighted\ aggregation\ of\ labour\ and\ capital\ input\ index}$$[7]

MFP measures are developed originally for the purpose of analyzing long-term productivity growth. It assesses the difference between the growth in the volume of output and the growth in the volume of inputs. This difference reflects more than just technical progress, it involves economies of scale; reallocation of inputs; changes in human capital; variations in capacity utilisation; climate events; and measurement error. Year-to-year changes also contain 'noise' that is distinct from the notion of technical progress.

MFP measures are compiled in the standard growth accounting framework, which originates from the neoclassical theory of economic growth formulated by Solow. The theory uses a translog production function in conjunction with two assumptions: constant returns to scale (i.e. double the inputs will double the outputs); and that the marginal products of capital and labour are equal to their respective real market prices (i.e. perfect competition).

These assumptions are unlikely to hold in practice. If there are scale efficiencies, then this will also be captured as an increase in MFP. This is considered an issue for the NZ construction sector as there would be many small firms operating in an environment of increasing returns to scale, especially over short periods. The implication is that the true productivity growth for construction in NZ has been overstated from this perspective alone.

The modern growth accounting framework is characterized by the incorporation of quality changes into the measurement of capital and labour. Unfortunately, as indicated previously, the labour input is measured by unadjusted hours paid. The part of technical progress captured in constant quality of input indexes is referred to as embodied technological progress, while disembodied technological progress relates to spill-over effects through the diffusion of advances in science and technology. Without input indexes of constant quality, the inability to distinguish between the two is another issue for NZ construction.

One should also be cautious about the practical implications of official productivity statistics, they are not as straightforward as they look. One example is the *inter-industry* productivity comparison. According to the official statistics, labour productivity (as measured by industry real GDP generated per hour of standardised labour units being paid) was up 170 per cent and 160 per cent for the NZ Agriculture and Forestry sectors respectively, while the Building and Construction sector lagged behind with growth of just 23 per cent between 1978-2011.

However, do these findings imply that the economy should put a pause in building activities and shift the resources to primary sector production? Both Agriculture and Forestry have benefited from multiple technological innovations since 1980s (fertiliser, feeding, breeding, and automation technologies). All of which resulted in fundamental changes in the production processes and the resulting productivity measures were reflections of these technological breakthroughs. Construction

[7] The weights used are their corresponding income shares.

practices have not changed radically in 40 years (Rice and Forgan, 2016), at least the change was to a much lesser extent due to the "Building and Construction" classification upon which all official statistics and reference analysis have been build (i.e. the Australian and New Zealand Standardized Industrial Classification 2006).[8] Nonetheless, this didn't imply that Building and Construction was a less relevant sector.

Another paradox is the comparison of construction productivity trends across countries. Such exercises might provide useful insights if accompanied by appropriate acknowledgements of the comparability issues. *Inter-country* productivity comparisons could indicate that better training and production systems are available, and innovative policies and regulations could be introduced into NZ. But it is important to be aware of that inter-country comparisons are notoriously difficult in practice.

In a recent critique of international comparisons, Vogl and Abdel-Wahab (2015) indicate that these productivity estimates do not compare like for like. Data definitions and coverage differ substantially across countries. In addition, deflators and exchange rates used to convert output into a common currency are unreliable. These problems exist even for countries with many similarities concerning infrastructure. To illustrate a few: (1) the StatsNZ derives its labour input index from *hours paid* while the Australian Bureau of Statistics provides the labour index based on *quality adjusted hours worked*; (2) Eaqub (2013) reports that construction in NZ makes much greater use of forest products, architectural and related services, suggesting more customized homes compared to Australia; and (3) in a comparison of productivity between Canada and the U.S., Nasir *et al.* (2013) found despite the fact that these two countries share the same language, union organization, building design styles, equipment spreads, and highly coupled broader economies, the U.S. construction sector had stagnated, while its productivity was growing in Canada. This was potentially due to differentials in wages and training systems.

To address the challenge of developing more practical industry performance indicators for the formulation and evaluation of effective policies, the KLEMS MFP could be tested as the next solution. This measure has been developed and advocated by other national statistical bureaus including the U.S., Canada, Japan, Korea, the EU, India, China, Brazil and Argentina.

## 2.3 Industry-level KLEMS MFP

The advantages of this approach have been discussed in several studies for the EU (Abdel-Wahab and Vogl, 2011; Ruddock and Ruddock, 2011; Sezer and Bröchner, 2014). KLEMS refers to the five inputs considered in the construction of MFP, which include capital (K), labour (L), energy (E), materials (M) and services (S), and a gross output measure (instead of the value-added output measure) is used. Separately identifying energy, materials and services is useful as each of the inputs

[8] The Australian and New Zealand Standard Industrial Classification (ANZSIC) was developed by Statistics New Zealand and the Australian Bureau of Statistics in the 1990s to reflect the structure of Australian and New Zealand industries and improve the comparability with other countries' statistics. ANZSIC06 is currently being integrated into Statistics New Zealand's collections and is the classification system upon which all referenced analyses have been built.

have distinctly different roles in the production process. Currently, there are no attempts in NZ to experiment with the KLEMS MFP measure. The implications on productivity growth are likely to be complicated, especially for industries like Building and Construction, with major supply chain activities being carried out in other sectors (or migrated to other sectors as a result of recent technical progress). The KLEMS MFP offers more information on the inputs contributing to output growth and production efficiency, it informs policymakers and economists through identifying factors of economic growth, such as structural changes in the industry's input mix (particularly with regards to the relative contribution from intermediate inputs).

Taking the intermediate inputs reflecting renting, hiring and out-sourcing as an example. An industry's reliance on primary inputs relative to intermediate inputs may change due to changes in leasing and hiring arrangements rather than the production process itself. When capital is rented under an operational lease arrangement from a firm in another industry, the use of the capital is classified as an intermediate input of the lessee. A construction company may lease a crane from the rental and hiring industry, which is recorded as a service component in the intermediate inputs of the lessee and as capital services held by the lessor in the rental and hiring industry (ANZSIC06 – L66). Another example is the off-site production of prefabricated buildings or building components, they are not recorded in construction (ANZSIC06 – E), but in structural metal product *manufacturing* (ANZSIC06 - C222). Architectural or building consultancy services are recorded in architectural, engineering and technical *services* (ANZSIC06 - M692). Many other intermediate inputs, such as timber and plumbing goods consumed on-site, are recorded in wholesaling (ANZSIC06 - F333). We mentioned previously that Eaqub (2013) reports construction in NZ makes much greater use of forest products, architectural and related services. Construction productivity growth experienced by these parts of the value chain however would not be captured in existing MFP analysis that excludes these critical intermediate inputs.

## 3. Firm-level Performance Measures

Performance at the firm-level can also be examined using indexes of productivity ***change***, or measures of productivity ***level***. A summary has been provided in ***Table 2***, decomposition of total factor ***productivity*** (TFP) ***change at the firm-level*** is less common relative to industry-level measures. Only a few evaluations can be found in scientific journals such as the *Journal of construction engineering and management*, *construction management and economics*, and *Journal of Productivity Analysis etc.* This limited availability of firm-level studies is mainly attributed to the research capacities required for applying advanced methodologies on large administrative datasets.

Nonetheless, there are major advantages associated with performance analysis at the firm-level. It provides more *actionable knowledge* and an ***improved*** *lens to understand the drivers of productivity growth*. This is accomplished through constructing the production frontiers which characterize the unobserved technologies representing the industry's best practices. Then the process of determining deviations from the established frontiers by individual or clusters of construction firms would lead to practical productivity-enhancing policies and strategies, i.e. identifying high-performing construction businesses and promoting their growth.

### Table 2 – Summary of Firm-Level Performance Measures

| Performance Measures (Firm Level) | Key Users | Purposes | Methodologies and Data | Assumptions and Issues | Recommendations |
|---|---|---|---|---|---|
| **Malmquist Index of Total Factor Productivity *Change*** | ***Government Agencies:***<br>***Treasury, MBIE (Building and Energy), Productivity Commission, Statistics New Zealand, Ministry of Housing and Urban Development, Housing New Zealand.***<br><br>***Industry Practitioners:***<br>***BRANZ, , Construction Sector Accord, Construction Industry Council.***<br><br>***Construction Businesses:***<br>***Kiwibuild, Fletcher, HEB Construction, Fulton Hogan, Tokin+Taylor, Naylor Love.***<br><br>Decomposition of ***total factor productivity (TFP) change*** at the firm-level is less common compared to industry-level measures. They are usually studies published in scientific journals such as the ***Journal of construction engineering and management***, ***construction management and economics***, ***Journal of Productivity Analysis*** *etc.* Its limited availability can be mainly attributed to the ***advanced techniques*** involved in analyzing large sets of firm-level data, such as ***DEA*** , ***SFA*** in combination with ***other econometric techniques***.<br><br>There are several decompositions of the Malmquist Index that have been developed in the literature. The most commonly referred is Färe *et al.* (1992) that decomposes the Malmquist TFP Index into ***two sources of productivity change***:<br>• ***technical efficiency change*** under constant returns to scale<br>• ***technological change***<br><br>Färe *et al.* (1994) further breaks down the component of technical efficiency change into:<br>(1) ***Technical efficiency change*** under *variable returns to scale*<br>(2) ***Scale efficiency change***<br><br>The variable returns to scale (VRS) assumption in the technical efficiency component allows for an appropriate treatment of a firm's heterogeneity related to size. Simar and Wilson (1998) and Zofio and Lovell (1998) determined that to obtain a meaningful economic interpretation of all components of productivity change, it would be useful to assume the VRS to be the benchmark technology when calculating the technological change component. To do so, they decomposed the technological change component in Färe *et al.* (1992, 1994) into:<br>(3) ***Technological change*** under VRS<br>(4) ***Scale change of the technology***<br><br>The values of the input-oriented Malmquist Index and its components that are less than 1 indicate improvements in productivity. | These ***insights*** gathered ***into the frontier building technology*** would provide policymakers and industry practitioners with ***more actionable knowledge and an improved lens to understand*** the ***drivers of productivity growth*** , such as what kind of policy initiatives/industry support would work in practice to enhance productivity, towards what areas and by how much.<br><br>This is accomplished through ***constructing the frontiers which characterize the unobserved technologies representing the industry's best production practices***. Then the process of determining deviations from the established frontiers by individual or clusters of construction firms would lead to effective policies and strategies, i.e. ***identifying high-performing construction businesses and promoting their growth.*** | Productivity growth assessed by means of Malmquist Index is formulated on the basis of distance functions. ***Distance functions*** allow one to describe a multi-input, multi-output production technology without the need to specify a behavioral objective.<br><br>An input-oriented distance function characteritizes the production technology by looking at a maximal proportional contraction of all inputs, given outputs produced. An output distance function considers a maximal proportional expansion of the output vector, given the inputs consumed.<br><br>There are a number of different methods that could be used to estimate a production technology and, hence, measure the distance functions that make up the Malmquist TFP index. To date, the most popular method has been the ***Data Envelopment Analysis (DEA)***, complemented by bootstrap to assess the statistical precision of the indices computed using DEA. Alternative approach is the ***Stochastic Frontier Analysis (SFA)***.<br><br>Besides methodological approach, another key issue in constructing firm-level performance measures is the availability of ***input-output volume data*** . In the case of multiple inputs and multiple outputs, it is important to ***account for heterogeneous units and quality change*** over time.<br><br>In practice, ***firm-level data is often available in the form of financial statements/accounts***. As a result, revenue or sales are often used as proxy volume measures for outputs, deflated using a price index of the corresponding output in the construction industry. Employee costs, material costs and fixed assets are used as proxy volume measures for inputs, all deflated using the corresponding price index created by national statistical agencies. | ***DEA*** essentially involves the use of ***linear programming methods*** to construct a nonparametric piece-wise surface (or frontier) over the data. DEA has been chosen in the majority of studies decomposing construction productivity growth, as evidenced in the literature review table generated by De Jorge Moreno *et al.* (2016). The advantages include:<br><br>(1) It ***does not require the specification of a functional form (Cobb-Douglas or Translog)*** to represent the underlying production technology;<br><br>(2) It ***does not require distributional assumption*** for inefficiencies across firms. Therefore the resulting non-parametric piece-wise frontier constructed with DEA envelops the observations more closely, in other words, it gives us ***a more flexible representation of the production frontier*** whose shape is largely determined by the actual observations instead of the arbitrary properties and constraints imposed by theory.<br><br>It is considered to be ***a better approach to fulfill the objective of identifying the sources and contributions of productivity growth without necessarily understanding the scope for attainable improvements***. | There are many venues to make contributions to firm-level productivity studies. Minor additions to existing studies include:<br>(1) ***Testing more flexible function forms*** as they may allow better approximation of the underlying true production possibility frontier;<br><br>(2) ***Utilizing advanced methodological approach and large administrative database*** (i.e. LBD and IDI) for ***more rigorous analysis***. Simple regression technique, such as the OLS employed in available studies, does not offer the advantages associated with the standard techniques employed in the field of productivity and efficiency analysis. More specifically, it has neither the structural flexibility offered by the nonparametric technique such as DEA, nor the capability of accounting for noise in the data as the parametric SFA does.<br><br>Besides these minor additions, we reckon it is important to perform firm-level empirical analysis that could:<br>(3) ***Further decompose productivity growth*** into various ***channels***;<br><br>(4) ***Compare*** different industry practices and ***identify the best technologies and clusters;***<br><br>(5) ***Investigate the determinants of efficient construction firms***. |
| **Technical Efficiency *change*** | | Measures the extent to which the evaluated firm is getting closer or further from the VRS best practices frontier (so called catching up effect). | | | |
| **Scale Efficiency *change*** | | Measures the movement of the production unit toward or away from the technically optimal scale. | | | |
| **Pure technological *change*** | | Measures the shift in the VRS best practice frontier between different time periods. | | | |
| **Scale *change* of technology** | | Reflects the shift in the optimal scale of technology between different time periods. | | | |
| **Technical Efficiency level** | Studies with a primary focus on ***quantifying the gains from a better utilization of the production process*** would measure performance level instead of performance change.<br><br>They are carried out to ***characterize efficient construction companies*** and ***investigate the determinants of high performance***.<br><br>Unlike productivity, efficiency is a relative concept, relative to the best practice frontier estimated using firm observations. The overall economic efficiency for a firm consists of three multiplicative components. | **M**easures the ability of a firm to obtain maximum outputs given the inputs used, or the ability to use minimum inputs given the outputs produced. | As this benchmarking exercise involves the ***explicit characterization of production technology***, it is important to ***categorize firms of similar nature into the same*** group to ensure the technological representation truly approximates the ***production possibility frontier***.<br><br>The frontier estimated using a simple OLS regression by Jaffe *et al.* (2016) is conceptually equivalent to the index number approach used by Statistics NZ to calculate MFP. The weights in the index number approach are prices or income shares, whereas in this approach they are the parameters associated with inputs. Furthermore, these estimated parameters represent the output elasticities associated with each input.<br><br>As evidenced in limited NZ studies (Fabling and Maré, 2015b, Fabling and Sanderson, 2016, Jaffe *et al.* 2016, Jaffe and Chappell, 2018), firm-level performance analysis could utilize existing ***administrative datasets in the Longitudinal Business Database (LBD) and Integrated Data Infrastructure (IDI)***.<br><br>The LBD comprises tax-and survey-based financial data, employment data, merchandise and services trade data. These data sources are linked together through the Longitudinal Business Frame (LBF). The LBF is a register of all economically significant businesses in NZ (i.e. with annual turnover of at least $30,000), refer to Fabling and Sanderson (2016) for detailed description. | ***SFA*** is considered to be a better approach for investigating the characteristics and determinants of efficient construction firms because<br>(1) DEA does not ***account for noise in the data or random effects in the production process***, impacts of the latter is considered important during the building process;<br>(2 ) DEA does not ***provide parameter estimates characterizing the underlying production technology*** , such as estimated labor output elasticities, returns to scales etc.<br><br>Among other commonly used econometric techniques such as OLS, SFA approximates the production technology with certain assumptions for the sake of simplicity such as:<br>(a) The commonly utilized Cobb-Douglas functional representation of the production technology is likely to be inadequate;<br>(b) Constant marginal contribution to productivity is assumed for all firms within a sub-sector. In certain sub-sectors, such as housing construction, over two-thirds of the firms in the industry are working proprietor only firms - it is therefore questionable if they share the same technology and should be represented using the same production function. There is no way to ascertain how much time the owner has spent on the business, one unit of working proprietor is likely to be very different from one unit of employee for employing firms. This is evident in Jaffe *et al.* (2016) when they run separate regressions for working proprietor only firms and employing firms. The estimated parameters associated with labor input (i.e. output elasticity with respect to labor input) deviate substantially across the two sub-groups;<br>(c) The observation that new working proprietor only firms have higher productivity performance is not necessarily due to these firms' substantial commitment and managerial skills, it could be the result of a heating property market encouraging more entries and rising housing prices driving up the measured output (even after deflation). This may lead to a spurious result of increasing MFP. | |
| **Allocative Efficiency level** | | Measures the ability of the firm to choose the least cost input bundles to produce a given level of outputs, providing that the factor inputs markets are perfectly competitive, and firms are aware of (but do not have control over) the prevailing factor prices. | | | |
| **Scale Efficiency level** | | Measures the ability of the firm to operate at the optimal scale of production (which is the scale that corresponds to maximum outputs/inputs ratio, i.e. productivity). | | | |

Utilizing data of firm financial accounts, recent studies of the Spanish construction industry (De Jorge Moreno *et al.* 2016; Kapelko *et al.* 2014; Kapelko and Lansink, 2015; Kapelko and Abbott, 2017) indicate that productivity change in construction is not uniform across sub-sectors. This is due to the fundamental differences in competition, the nature of clients, the size of projects and firms involved. Bundling the sectors together in an industry-level analysis without accounting for the composition of the industry, could therefore be problematical. These studies further reveal that the Spanish building sub-sector experienced a productivity decline during 2000-2010 because of deteriorated technical and scale efficiency performance, these indicators reflect the managerial ability of the operator. In the meantime, there was technological progress, and the adoption of new best practice would offer considerable gains.

Furthermore, efficient construction firms were more resilient during an economic downturn and they were characterized by high capital intensity (i.e. low input ratio for labor and materials) and labor skills. These findings are in accordance with the conclusion of a NZ study (Jaffe *et al.* 2016), new firms started with higher productivity, but performance fell over time. This situation continued for a few years in Spain and eventually performance picked up when new construction companies survived the test of time and became more developed. Whether the NZ construction shares similar experiences is yet to be explored, we have no knowledge of studies in NZ that follow up productivity change for new starters.

Several decompositions of the Malmquist Index are available to measure productivity change at the firm-level, the most commonly referred approach is developed by Färe *et al.* (1992) which identifies two sources: *technical efficiency change* under constant returns to scale (CRS), and *technological change*. The decomposition of Färe *et al.* (1994) further break down the component of technical efficiency change into technical efficiency change under variable returns to scale (VRS) and scale efficiency change:

- ***Technical efficiency change*** measures the extent to which the evaluated firm is getting closer or further from the VRS production frontier representing current best practice (so called catching-up effect);
- ***Scale efficiency change*** measures the movement of the production unit toward or away from the technically optimal scale.

The VRS assumption in the technical efficiency component allows for an appropriate treatment of a firm's heterogeneity related to size. Simar and Wilson (1998) and Zofio and Lovell (1998) further establishes that to obtain a meaningful economic interpretation of all components of productivity change, the VRS frontier should be used as the benchmark technology when calculating the technological change component. They decomposed the technological change component in Färe *et al.* (1992, 1994) into technological change under VRS (so called pure technological change), and the residual measure of the scale change of the technology:

- ***Pure technological change*** measures the shift in the VRS best practice frontier;

- ***Scale change of the technology*** reflects the shift in the optimal scale of technology.[9]

Using this technique, Kapelko and Abbott (2017) finds that during the period of 2000-2010, the Spanish construction firms engaged in the building construction sector not only became less technically efficient (a decline of 20%), but also were further away from the constant returns to scale portion of technology (a decrease of 8% in scale efficiency). However, the indexes that composed the technological part of the Malmquist index showed opposite effects; the industry's production frontier showed considerable outward expansion, resulting in an average pure technological progress of 16%. The index that measures the scale change of the technology also showed an improvement of 6%.

These evidences suggest there were large gains offered by new building technology, if adopted at an appropriate scale by construction firms in Spain. Meanwhile, potential improvements in the efficient utilization of existing technology were also substantial and should not be overlooked. During periods of high demand, targeting both the winners and dawdlers could yield significant productivity growth. During periods of economic downturn, the dawdlers are likely to exit the market, but it is important to encourage survivors to invest in new design and technologies for retaining competitive advantage and sustaining productivity growth.

Productivity growth assessed by means of Malmquist Index is formulated based on distance functions. Distance functions allow one to describe a multi-input, multi-output production technology without the need to specify a behavioral objective. An input-oriented distance function characterizes the production technology by looking at a maximal proportional contraction of all inputs, given outputs produced. An output distance function considers a maximal proportional expansion of the output vector, given the inputs consumed. There are several techniques for constructing the benchmark production frontier and, hence, measuring the distance functions that make up the Malmquist TFP index. To date, the most popular methodology has been the Data Envelopment Analysis (DEA), complemented by bootstrap to assess the statistical precision of the indices computed using DEA.

DEA essentially involves the use of linear programming methods to construct a non-parametric piece-wise surface (i.e. frontier) over the data. It has been chosen in many studies measuring productivity growth in the construction industry, as documented in a recent survey (De Jorge Moreno *et al.* 2016). The advantages of using DEA include (1) it does not require the specification of a functional form (e.g. Cobb-Douglas or Translog)[10] to represent the underlying production technology; and (2) it does not require any distributional assumptions for inefficiencies across firms.

[9] The values of the input-oriented Malmquist Index and its components that are less than 1 indicate improvements in productivity.

[10] Different algebraic relationships between outputs and inputs give rise to different functional forms. Cobb-Douglas and Translog are the two most commonly adopted production functions in production economics. Both satisfy the strong essentiality property of a production technology. In other words, both assume that every input included in the production function is essential. And both satisfy the monotonicity property provided the first-order coefficients are non-negative. The monotonicity property of a production function says that additional units of an input will not decrease output. If the production function is continuously differentiable, monotonicity implies all marginal products are non-negative.

Therefore, the technological frontier constructed using DEA envelops the observations more closely. In other words, it gives a more flexible representation of the production frontier whose shape is largely determined by the actual observations instead of the arbitrary economic properties and constraints imposed by theory. As a result, DEA is a better approach for identifying the sources and contributions of productivity change without necessarily understanding the scope for attainable improvements.

Studies with a primary focus on quantifying the gains from a better utilization of the production process would measure performance level instead of performance change, they are carried out to characterize efficient construction companies and investigate the determinants of efficiency performance. Unlike productivity, efficiency is a relative concept, relative to the best practice frontier estimated using firm observations. The overall economic efficiency for a firm consists of the following three multiplicative components:

- ***Technical efficiency*** measures the ability of a firm to obtain maximum outputs given the inputs used, or the ability to use minimum inputs given the outputs produced;
- ***Allocative efficiency*** measures the ability of a firm to choose the least cost input bundle to produce a certain level of outputs, providing that the factor inputs markets are perfectly competitive, and firms are aware of but do not have control over the prevailing factor prices;
- ***Scale efficiency*** measures the ability of a firm to operate at the optimal scale of production (which is the scale that yields the maximum outputs/inputs ratio).

As this benchmarking exercise involves the explicit characterization of production frontier, it is important to categorize firms of similar nature into the same group to ensure the technological representation truly approximates the production possibility frontier. The frontier estimated using a simple OLS regression by Jaffe *et al.* (2016) is conceptually equivalent to the index number approach used by StatsNZ to calculate MFP. The weights in the index number approach are prices or income shares, whereas in the frontier approach they are the parameters associated with inputs and estimated using econometric techniques. These parameters also represent the output elasticities associated with each input, which are the percentage change to outputs corresponding to a single percentage change in any of the inputs.

Regarding the methodological approach, the parametric SFA is a better choice for configuring the economic properties of the underlying production technology because (1) DEA does not account for noise in the data or random effects in the production process, the impacts of the latter are

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Cobb- Douglas is also concave in the inputs vector providing the monotonicity property is satisfied. Concave in inputs (i.e. the technology is convex) implies that all marginal products are non-increasing, the well-known law of diminishing marginal productivity. Its popularity in empirical applications is due to its simplicity, but this comes at the cost of losing flexibility. The elasticity of substitution is unity, the output elasticity and returns to scale are assumed to be fixed.

Translog, on the other hand, is favoured for its ability to provide a second-order differential approximation at a single point. However, this increased flexibility comes along with possible violation of convexity and the problem of having more parameters to estimate.

considerable in Building and Construction; and (2 ) DEA does not provide parameter estimates characterizing the production frontier, such as output elasticities and returns to scales *etc.*

Finally, another key issue in the measurement of performance at the firm-level is the availability of input-output volume data. In the case of multiple inputs and multiple outputs, it is important to account for heterogeneous units and quality change over time. In practice, firm-level data is only available in the form of financial statements/accounts. This means revenue or sales are often used as proxy volume measures for outputs. Employee costs, material costs and fixed assets are used as proxy volume measures for inputs, deflated using the corresponding price indices at the aggregate level. These price indices are part of the national accounts routinely produced by StatsNZ.

## 4. Project-level Performance Measures

Project/activity-level analysis treats different tasks in a construction project as different production processes that each requires a different specification of technology. Such analysis is usually performed using data manually collected on-site. The decision-making unit is less obvious; a firm might experience low productivity even if activity-level productivity is excellent due to low efficiency in project management. Professionals carry out activity-level studies and reviews are construction engineers. We present in ***Table 3*** a few selected examples of performance measures developed at the project/activity-level. The clients who would benefit the most from such studies are professional workers in building and construction businesses, instead of policymakers and industrial practitioners. The focus is process efficiency, improvements in the standard time spent on different on-site construction activities (e.g. hours per cubic meter of concrete), or daily installed outputs. These are physical performance indicators instead of economic measures.

One such example is the RSMeans Construction Cost Data from Gordian, North America's leading construction cost database. It serves as a common industry standard for determining the costs of construction projects of all types and sizes. RSMeans data is used by construction professionals to create budgets, estimate projects, validate their own cost data and plan for ongoing facilities maintenance. The RSMeans Data software publishes productivity data for most activities listed in the software manuals. The productivity data include daily output (the typical number of units the designated crew will install in a standard 8-hour workday) as well as labour hours (the number of labour hours required to install one unit of work) for each activity.

## Table 3 – Summary of Project/Activity Level Performance Measures

| | Performance Measures (Project/Activity Level) | Key Users | Purposes | Methodologies and Data | Recommendations |
|---|---|---|---|---|---|
| On-site Process Efficiency (e.g. Lean Production in Construction) | (1) Total hours (i.e. cycle time) spent on each activity;<br><br>(2) Total hours spent on the entire process involving different activities;<br><br>(3) Percentage of time spent on non-value-adding and unnecessary (NVAU) or ***wasteful activities*** across each activity, and across the whole process. The aggregate results show that the proportion of time spent on value-adding (VA) activities was 21 percent, while 55 percent of time is used in NVAU activities. Therefore, a comparatively high percentage of workers' time is spent on waiting, rework, transportation and motion that add no value. | ***Industry Practitioners:***<br>BRANZ, Housing New Zealand, Construction Sector Accord, Construction Industry Council, Engineering NZ, Master Builders (MB).<br><br>***Construction Businesses:***<br>Kiwibuild, Fletcher, HEB Construction, Fulton Hogan, Tokin+Taylor, Naylor Love.<br><br>Vilasini, N., Neitzert, T., & Rotimi, J. (2014). Developing and evaluating a framework for process improvement in an ***alliance project*** : A New Zealand case study. *Construction Management and Economics*.<br><br>The clients who are likely to benefit from such studies are ***on-site managers***, instead of high level policymakers. The associated measures are not derived from economic theories but physical on-site measures. | Investigates the extent to which the lean concept (waste reduction in particular) can be applied to projects executed using the alliance procurement system.<br><br>Define a framework to ***streamline improvements in processes*** and to verify the applicability of the defined framework to a real construction alliance project.<br><br>**Process level activities considered include:**<br>• Rebar cage fabrication<br>• Rebar cage lifting<br>• Mould set-up<br>• Survey (segment, pre-pour, as-built)<br>• Concrete pouring<br>• Crack segment<br>• Remedial work<br>• Transfer to yard<br>• Final inspection | Using the ***principle behind waste activity classification***, the observed working hours spent on each activity are divided into:<br>(1) ***value-adding (VA) activities*** that add value for the customer;<br>(2) ***non-value-adding necessary (NVAN) activities*** that do not add value for the customer but are considered to be necessary;<br>(3) ***non-value-adding and unnecessary (NVAU)*** or ***wasteful activities.***<br><br>The data was collected through ***process study***, i.e. spending time onsite to observe the construction process, identify improvement opportunities and conducting informal interviews with project team participants. | Develop a framework to streamline improvements in processes and to verify the applicability of the established framework to real construction projects of different types and scales. |
| Building Information Modeling (BIM) | Building Information Modelling (BIM) is a digital representation of the physical and functional characteristics of a building. BIM adds value to the whole life of a built asset, from inception to operation. A BIM model can contain information/data on design, construction, logistics, operation, maintenance, budgets, schedules and much more. The information contained within BIM enables richer analysis than traditional processes. Information created in one phase can be | ***EBOSS & BIM Acceleration Committee*** (2019). BIM in New Zealand - an industry-wide view 2019 (Baseline information of BIM across the New Zealand construction industry).<br><br>BIM Acceleration Committee (2019). New Zealand BIM Handbook. BIM provides benefits to a wide range of ***construction professionals*** **such as architects, designers, quantity surveyors and facility** | BIM is not any single act or process. It is not creating a 3D model in isolation or utilizing computer-based fabrication. It is being aware of the information needs of others as you undertake your part of the process. | BIM covers ***a number of processes or tasks,*** the top ten uses include:<br>3D coordination; Design Review; Existing Conditions Modeling; Design Authoring; Cost Estimation; Record Modeling; Site Analysis; Construction System Design; Asset Management; and Structural Engineering Analysis.<br><br>***The particular inputs (i.e. information/data) into a BIM model and the output(s) generated depend on the particular process or task*** . | Over time, the information collected through BIM could be utilized to create a common industry standard, similar to the RSMeans used in the U.S., for determining the cost of NZ construction projects of all types and sizes. |
| RSMeans Building Construction Cost Data | RSMeans Data is a ***construction cost estimating software*** which publishes productivity data for most activities listed in the software manuals.<br><br>The productivity data include ***daily output and labour hours for each activity*** .<br><br>The daily output represents the typical number of units the designated crew will install in a normal 8-hour workday.<br><br>The labour-hours figure represents the number of labour hours required to install one unit of work. For example, hours per cubic meter of concrete placed in a category of building element, such as footing. | Nasir, H., Ahmed, H., Haas, C., & Goodrum, P. M. (2014). An analysis of construction productivity differences between Canada and the United States. *Construction Management and Economics*.<br><br>Vereen, S. C., Rasdorf, W., & Hummer, J. E. (2016). Development and Comparative Analysis of construction industry labour productivity metrics. *Journal of Construction Engineering and Management*.<br><br>Construction professionals who are likely to benefit the most are ***project managers and quantity surveyors.*** | The RSMeans is a common industry standard used in the U.S. for determining the cost of construction projects of all types and sizes. | Physical measures such as installed quantity for outputs measured in corresponding units.<br><br>Labour: hours spent on each activity.<br><br>Labour costs: cost ($) associated with each activity.<br><br>Equipment costs: cost ($) associated with each activity. | Develop a similar common industry standard in New Zealand for construction professionals to create budgets, estimate projects, validate their own cost data and plan for ongoing facilities maintenance. |
| Last Planner System (LPS™) | The Last Planner System (LPS™), developed by Ballard (2000), is another ***production planning and control system*** based on lean production principles which leads improvements in processes for ***on-site managers***. It has been increasingly applied in the construction industry to improve planning reliability, reducing the negative impacts of variability. | Gonzalez, V., Alarcon, L. F. & Mundaca, F. (2008). Investigating the relationship between planning reliability and project performance. *Production Planning & Control.*<br><br>LPS™ benefits clients of ***construction project management*** . | Two indexes are proposed in the referred study: Process Reliability Index (PRI), and a Project Productivity Index (PPI). The study quantifies the significance of the relationship between planning reliability and project performance in a construction project where LPS™ was applied. | Daily production rates and labour productivity for each activity were collected.<br><br>Process Reliability Index (PRI) consists of: (1) actual progress for each week and activity; (2) planned progress for each week and activity.<br><br>Project Productivity index (PPI) consists of: (1) activity productivity index for each week and activity; (2) number of activities with labour productivity information available for each week.<br><br>Activities being analyzed include: Concrete, Stucco, Roof structure, Eaves, Tiles installation, Interior painting – varnish, Interior painting – 1st Layer, Interior painting – 2nd Layer; Exterior painting, and Wall-sealing. | Experiment a similar production planning and control system tailored for New Zealand to improve on-site process efficiency. |
| Work Sampling Proportions (WSPs) | Before improvement strategies can be proposed and implemented to improve labour productivity, construction representatives need an activity-level ***construction labour productivity (CLP)*** model that enables them to fully understand which ***parameters (factors and practices) cause productivity to change*** and by how much. | Tsehayae, A. A. & Fayek, A. R. (2016). System model for analysing construction labour productivity. *Construction Innovation.*<br><br>***On-site managers*** can learn from the findings and reformulate their use of direct work proportions and activity models for predicting and improving CLP. | Tsehayae and Fayek (2016) develops a list of 169 parameters (factors and practices) influencing CLP. The input parameters are grouped into a hierarchal structure and classified according to six levels: (1) activity; (2) project; (3) organisational; (4) provincial; (5) national; and (6) global.<br><br>Process variables include those stated in the CII Guide to activity analysis (2010); namely direct work, preparatory work, tools and equipment, material handling, waiting, travel and personal.<br><br>Tsehayae and Fayek (2016) found that process variables, or working sampling proportions (WSPs), do not directly affect CLP but rather strengthen the influence of the input parameters on CLP. | The system model parameters – comprising factors and practices – and work sampling proportions (WSPs) were identified from a literature survey.<br><br>Extensive data for input, process and output variables were collected from 11 projects across Alberta, Canada. Data collection took place between June 2012 and November 2014 in collaboration with six partnering companies.<br><br>Activity models based on the relationship between construction labour productivity (CLP) and WSPs were created, and their validity was tested using regression analysis for eight activities in the concreting, electrical and shutdown categories. The proposed system model was developed for concreting activity using the key influencing parameters in conjunction with WSPs. | Conduct similar studies in New Zealand through the collection of on-site data across different projects and advise on ways to improve on-site management. |

The NZ study conducted by Vilasini *et al.* (2014) tested something similar, to investigate the extent to which the lean concept (waste reduction in particular) can be applied to projects executed using the alliance procurement system. They collected data through a process study, i.e. spending time on-site to observe the construction process, identifying improvement opportunities and conducting informal interviews with project team members. The study defines a framework to streamline improvements in processes and to verify the applicability of the established framework to a real construction alliance project. The activities being evaluated include:

- Rebar cage fabrication
- Rebar cage lifting
- Mould set-up
- Survey (segment, pre-pour, as built)
- Concrete pouring
- Crack segment
- Remedial work
- Transfer to yard
- Final inspection

The observed working hours spent on each activity were divided into (1) value-adding (VA) activities that add value for the customer; (2) non-value-adding necessary (NVAN) activities that do not add value for the customer but are considered to be necessary; and (3) non-value-adding and unnecessary (NVAU) or wasteful activities. The proportion of time spent on VA activities was found to be only 21 per cent, while 55 per cent of the time is used in NVAU activities. Therefore, a comparatively high percentage of workers' time was spent on waiting, rework, transportation and activities that add no value.

Building Information Modelling (BIM) is another example which could provide better on-site coordination. It is a digital representation of the physical and functional characteristics of a building. A BIM model can contain information/data on design, construction, logistics, operation, maintenance, budgets, schedules and much more. The information contained within BIM enables richer analysis than traditional processes. Information created in one phase can be passed to the next for further development and reuse. A range of processes or tasks is covered in BIM with the top ten being:

- 3D coordination
- Design Review
- Existing Conditions Modelling
- Design Authoring
- Cost Estimation
- Record Modelling
- Site Analysis
- Construction System Design
- Asset Management
- Structural Engineering Analysis

The inputs (i.e. information/data) into a BIM model and the output(s) generated depend on the specific process or task. BIM is not any single act or process. It is not creating a 3D model in isolation or utilising computer-based fabrication. It is being aware of the information needs of others as one undertakes his part of the process. The information collected through BIM over time could be utilized to create a NZ RSMeans Data, i.e. a common industry standard for determining the cost of construction projects of various types and sizes.

The Last Planner System (LPS™) designed by Ballard (2000) is another production planning and control system based on lean production principles. It has been utilized in construction industry to promote actions that increase planning reliability and monitors the percentage of plan completed (PPC) in a short-term period. Gonzalez *et al.* (2008) investigated the relationship between planning reliability and project performance. They reformulated the classical metric of planning reliability to develop a complementary set of 'activity-based' indices, called process reliability index (PRI). On top of this, a set of 'project-based' aggregate labour productivity indices, called project productivity index (PPI), was constructed as performance indicators. The findings prove that the LPS™ could provide more control and stabilisation of the complex and dynamic environment in managing construction projects. The standard activities being analysed include:

- Concrete
- Stucco
- Roof structure
- Eaves
- Tiles installation
- Interior painting – varnish
- Exterior painting
- Wall-sealing
- Interior painting – 1st Layer
- Interior painting – 2nd Layer

In practice, before any improvement strategies can be proposed and implemented, construction representatives need a construction labour productivity (CLP) model that enables them to fully understand which parameters (factors and practices) cause productivity to change and by how much. Tsehayae and Fayek (2016) grouped these parameters into a hierarchal structure and classified them into six levels: (1) activity; (2) project; (3) organisational; (4) provincial; (5) national; and (6) global. The Guide to activity analysis (2010) identified process variables on construction sites according to:

- Direct work
- Preparatory work
- Tools and equipment
- Material handling
- Waiting
- Travel
- Personal

Tsehayae and Fayek (2016) found that these process variables, or working sampling proportions (WSPs), do not directly affect CLP but rather strengthen the influence of the various parameters. On-site managers therefore can reformulate activity models (i.e. their use of direct work proportions) for predicting and improving CLP.

# 5. Recommendations

Based on the discussions presented above, it is important to have performance or productivity measures across different levels for a variety of stakeholders and purposes. This section provides productivity-enhancing recommendations for measures at each of the assessment levels.

## 5.1 Industry-level Recommendations

We draw attention to three specific developments to improve productivity measures at the aggregate level.

### 5.1.1 Gross Output (GO) based MFP

The commonly discussed partial productivity measures and MFP are derived from *real* industry GDP, which is a value-added (VA) output measure. As mentioned in section 2.1.1, the value-added concept is developed to facilitate the comparison of productivity across different industries. This definition assumes that the components of value-added are separate from that of intermediate inputs. The assumption also implies a specific way that productivity growth affects the usages of primary and intermediate inputs, this is unlikely to be practical for Building and Construction.

In the productivity measurement literature, gross output (GO) based MFP is preferred as it is a natural output concept and consistent with the traditional production theory linking output to primary as well as intermediate inputs (i.e. requires less restrictive assumptions). Ideally, MFP measures 'disembodied technical change' attributable to improved use of factor inputs. In the case of gross output, this efficiency can be attributed to improvements in not only the use of primary inputs, i.e. capital and labour, but also in the use of intermediate inputs. Given how construction technologies evolved in the last few decades, the general conclusion of stagnated productivity growth is unlikely to remain the same when we factor in efficiency gains associated with the utilization of intermediate inputs or the technologies used to produce these inputs, e.g. nail guns and timber products.

Developing a gross GDP MFP alongside the existing real GDP MFP is therefore a straightforward way to provide a refined examination of growth trends in construction productivity. Another alternative is to explore data source beyond GDP oriented output measures. The building consents administrative data from the local councils might serve as a complementary source (e.g. distinguish between total floor areas of new stand-alone houses versus additions in housing renovation). But the feasibility depends on data linkage at the firm level, i.e. integration across the building consents data and the Longitudinal Business Database (LBD). This requires joint commitments from the government and the industry to work together in generating better productivity measures and better understanding of the existing measures.

### 5.1.2 Industry-level KLEMS

Another key recommendation for the NZ construction is to experiment the KLEMS MFP. As introduced in section 2.3, this is a more detailed industry performance indicator which adds value to the formulation and evaluation of productivity-enhancing industry policies. The KLEMS MFP has been developed and advocated by other national statistical agencies including the U.S., Canada, Japan, Korea, the EU, India, China, Brazil and Argentina.

The benefits of KLEMS MFP have been discussed in several studies for the EU (Abdel-Wahab and Vogl, 2011; Ruddock and Ruddock, 2011; Sezer and Bröchner, 2014). Separately identifying energy, materials and services is important for construction as each of the inputs have distinctly different roles in the production process. To the best of our knowledge, there are no attempts in NZ to investigate the KLEMS MFP measure but this is feasible. The Australian Bureau of Statistics sources the intermediate input indices (for energy, materials and services) and their respective shares from the supply-use tables (SUT), which Stats NZ also compiles annually as part of supply-use balancing.[11] This process reconciles the production and expenditure measures of gross GDP by balancing the flows of goods and services within the economy. The SUT is a powerful tool to compare and contrast data from various sources and improve the coherence of the economic information system. It reconciles the supply of products within the economy with their use for intermediate consumption, final consumption, capital formation, and exports. They permit an analysis of markets and industries and allow productivity to be studied at this level of disaggregation.

### 5.1.3 Alternative approaches for measuring productivity change

The final recommendation for industry-level measures is the utilization of alternative approaches, there are generally four approaches to measure productivity change.

The MFP index routinely produced by Stats NZ (discussed in section 2.2.) represents the first approach, which uses a measure of output growth, net of growth in inputs. This approach is known as the *Hicks-Moorsteen (HM) approach* in the literature.

The second approach is similar in nature, which measures productivity change using growth in profitability after adjusting for movements in input and output prices.

The third approach measures productivity by *comparing* the observed outputs produced within a given period with the maximum level of outputs that can be produced using current production technology. The resulting measure is referred to as the Malmquist total factor productivity (TFP) index as the comparison between observed outputs and maximum possible outputs are measured

[11] See Statistics NZ for more information.

using Malmquist input or output *distance* functions. This approach can be referred to as a production frontiers approach because it involves the construction of a frontier representing best practice and the benchmark against which performance (i.e. *distance*) is measured.

The Malmquist (i.e. the third approach) and HM TFP (i.e. the first approach) indices are defined using entirely different conceptual frameworks; they are equal if and only if the technology is inversely homothetic and exhibits constant returns to scale (CRTS). Efficiency change and technical change are the only two sources of productivity change under CRTS and these are all captured by the Malmquist TFP index. However, if a variable return to scale (VRS) technology is more appropriate, then the Malmquist TFP index fails to capture productivity change from all the different sources.

The fourth approach is a bottom-up, sourced-based tactic advocated by Balk (2001). It is the most comprehensive alternative procedure which starts with a list of all possible sources of productivity growth and then examines the best possible way of measuring each of these sources and combines them to derive a measure of productivity change.

In principle, which approach to select should depend upon: (1) the purpose of measuring productivity levels and productivity changes. For example, if only a summary measure of productivity changes is required, the MFP index routinely produced by StatsNZ using the HM approach is sufficient. If a more business-oriented approach is preferred, the use of changes in profitability ratios to measure productivity change is suggested; (2) empirical feasibility is another crucial determinant, a primal approach to productivity change – an approach based on the primal representation of technology (i.e. the Malmquist TFP index and component-based approach) requires a panel dataset which contains a large number of firms, large enough to provide a good description of the underlying production frontier; and (3) in circumstances where the issues of scale are not relevant (i.e. at aggregated level), it may be possible to assume that the production technology exhibits constant returns to scale. This is the case when international comparisons of productivity are made. If the technology exhibits variable returns to scale (VRS), the component-based approach outlined in Balk (2001) is recommended if data is available.

## 5.2 Firm-level Recommendations

There are many venues to add contributions to firm-level performance evaluations. As evidenced in the limited studies in NZ (Fa bling and Maré, 2015b; Fabling and Sanderson, 2016; Jaffe *et al.* 2016; Jaffe and Chappell, 2018), firm-level performance analysis could utilize administrative datasets in the Longitudinal Business Database (LBD) and the Integrated Data Infrastructure (IDI).[12] The existing

[12] The LBD comprises tax-and survey-based financial data, employment data, merchandise and services trade data. These data sources are linked together through the Longitudinal Business Frame (LBF). The LBF is a register of all economically significant businesses in NZ (i.e. with annual turnover of at least $30,000), one can refer to Fabling and Sanderson (2016) for a detailed description. It includes information on location, industry classification, business type (e.g. limited liability company, partnership), institutional sector (e.g. private enterprise, central government), and parent-subsidiary relationships etc. The live version of the database is called ibuldd_clean. Alongside the LBD database (ibuldd_clean) sits the ibuldd_research_datalab database. This is a repository in which datasets created by users are shared. The productivity dataset (Fabling and Maré,

empirical analyses experimented only simple econometric technique (i.e. Ordinary Least Squares regression), and they constructed production frontiers under certain restrictive assumptions which involve several issues:

a. The commonly used Cobb-Douglas functional representation of the production technology is likely to be inadequate. Flexible function forms such as the translog are recommended as they allow better approximation of the underlying true production possibility frontier;

b. Constant marginal contribution to productivity is assumed for all firms within a sub-sector. In certain sub-sectors, such as housing construction, over two-thirds of the firms in the industry are working proprietor only firms - it is therefore questionable whether they should be represented using a common production frontier. There is no way to ascertain how much time the owner has spent on the business; one unit of working proprietor is likely to be very different from one unit of employee for employing firms. This is evident in Jaffe *et al.* (2016) in which separate regressions were performed for working proprietor only firms and employing firms. The estimated parameters associated with labour input (i.e. labour output elasticity) deviate substantially across the two sub-groups;

c. Jaffe *et al.* (2016) also observed that new working proprietor only firms have higher productivity. This is not necessarily due to commitments and managerial skills (i.e. the supply side), it could be the result of a heating property market (i.e. the demand side) that encouraged small investors entering construction and measured output was driven up by rising housing prices (even after deflation). This may lead to a spurious result of increasing MFP.

Besides these minor recommendations, we consider it important to perform in-depth analysis that could (1) further decompose firm productivity growth into various channels; and (2) investigate the determinants of efficient construction firms. The purpose is to provide policymakers and industry practitioners with an improved lens to understand what kind of policy initiatives/industry support would work in practice in order to enhance productivity and by how much.

For instance, a rigorous firm-level productivity growth decomposition could identify the contribution from employing more advanced technology (i.e. new ways of building houses) versus the contribution from more efficient utilization of existing technology (i.e. eliminating waste under the existing way of building houses). The decomposition of MFP change in Jaffe *et al.* (2016) was performed at the industry-level (instead of firm-level). It highlights the benefits of greater competition but offers limited insights into how to promote productive firms.

As explained previously in section 3, different methodologies are available to accomplish the recommended analysis. To date, the most popular method for productivity growth decomposition has been the Data Envelopment Analysis (DEA), which essentially involves the use of linear programming methods to construct a non-parametric piece-wise frontier over the data. The idea is

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2015b) is a key example of user-derived data located in ibuldd_research_datalab, future research related to firm-level performance analysis could possibly utilize this dataset.

further illustrated in ***figure 1*** in which we consider a simple one input (denoted by *x*) and one output (denoted by *y*) scenario. The production frontier maps out the maximum output produced by different levels of input under the current state of technology (or the minimum input required to generate different levels of output).

**Figure 1 Graphical Representation of Production Frontiers constructed using DEA**

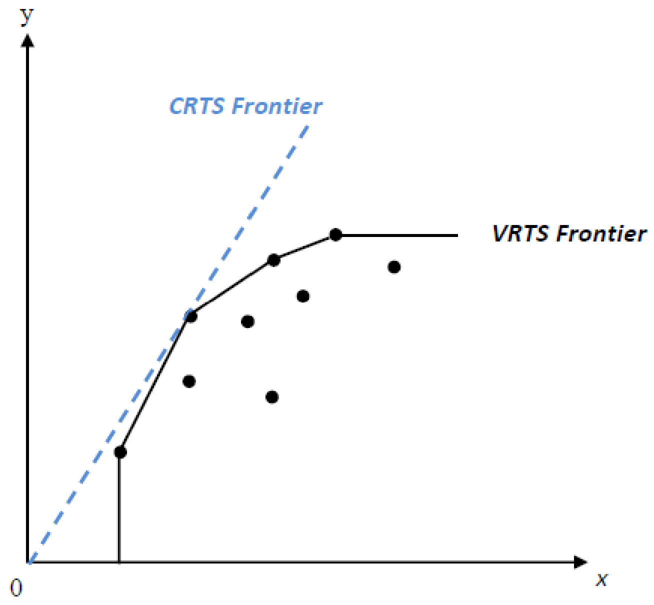
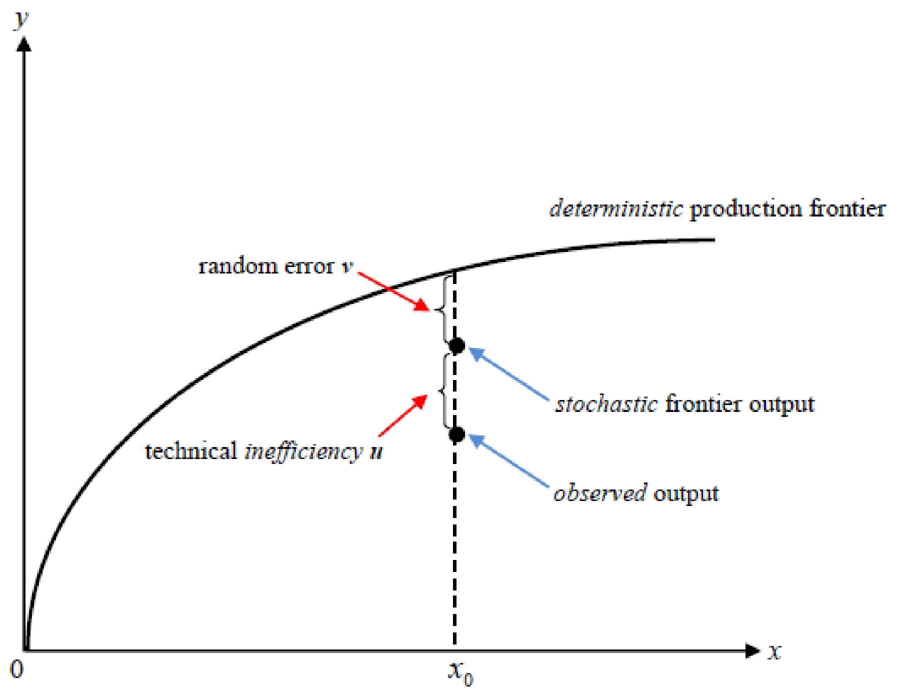



**Figure 2 Graphical Representation of Production Frontier constructed using SFA**




Although DEA has been chosen in most studies measuring *productivity growth* in Building and Construction, when the interests involve the understanding of the production technology itself, DEA has certain drawbacks compared to Stochastic Frontier Analysis (SFA). DEA does not account for noise in the data or random effects in the production process, impacts of the latter could be substantial in construction. And it does not provide parameter estimates characterizing the production frontier, such as output elasticities and returns to scales *etc.*

Stochastic Frontier Analysis is a better approach for understanding the economic properties associated with the production frontier and identifying efficient operating units. The idea is demonstrated in ***figure 2***, using once again the simple one input-output example. The distance from the observed output to the frontier output is partly due to inefficient production, and partly due to the negative random shocks experienced by the firm. It is possible for a firm to operate above the deterministic frontier if it experiences positive random shocks that are larger in magnitude than the inefficiency effect.

Simple regression technique, especially the commonly employed OLS (Fabling and Maré, 2015a and 2015b; Jaffe *et al*. 2016; Jaffe and Chappell, 2018), does not have the flexibility offered by the nonparametric technique DEA, nor the capability of accounting for noise in the data as the parametric SFA. We therefore recommend the utilization of more advanced techniques for future research related to firm-level productivity and efficiency evaluations.

## 5.3 Project and Activity-level Recommendations

Finally, at the project/activity level, we look at how the lean concept (waste reduction in particular) could be used in NZ Building and Construction for better process efficiency. We recommend: (1) collecting more on-site data across projects of different scales and types; (2) utilizing the information gathered through the Building Information Modelling (BIM); (3) developing a framework to streamline improvements in processes; and (4) ultimately creating a common industry standard to assist construction professionals such as architects, designers, quantity surveyors and project managers *etc.* An example of this is the RSMeans Building Construction Cost Data. The RSMeans data from Gordian is North America's leading construction cost database. A dynamic collection of data points actively monitored by experienced cost engineers, RSMeans data is used by construction professionals to create budgets, estimate projects, validate their own cost data and plan for ongoing facilities maintenance.

The RSMeans software is a construction cost estimating software which publishes productivity data for most activities listed in the software manuals. The productivity data include daily output and labour hours for each activity. The daily output represents the typical number of units the designated crew will install in a normal 8-hour workday. The labour-hours figure represents the number of labour hours required to install one unit of work. For example, hours per cubic meter of concrete placed in a category of building element, such as footing.

We are not aware of the availability of similar software for NZ Building and Construction, but the benefits are evident in the recent development of the Building Information Modelling (BIM). It is a digital representation of the physical and functional characteristics of a building and enables better on-site coordination. A BIM model can contain data on design, construction, logistics, operation, maintenance, budgets, schedules and much more. The information created in one phase can be passed to the next for further development and reuse. Over time, they could be utilized to create a NZ industry standard for determining the cost of construction projects.

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