Forest Growers Research Ltd
P.O. Box 1127
Rotorua 3040
Phone: 07 921 1883
Email:
forestgrowersresearch@fgr.nz
Web: www.fgr.nz

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Using Data Envelopment Analysis to explore productivity benchmarking in the New Zealand harvesting sector

Authors:
Okey Francis Obi, Agricultural & Bioresources Engineering Department, University of Nigeria
and
Rien Visser, School of Forestry, University of Canterbury

Research Provider:
School of Forestry
University of Canterbury
Te Whare Wānanga o Waitaha
Christchurch, New Zealand

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EXECUTIVE SUMMARY

A benchmarking system developed by Forest Growers Research Ltd., and managed by the University of Canterbury, School of Forestry has been recording cost and productivity for plantation forest harvesting operations in New Zealand over 10 years (2009 – 2018) with over 1500 unique entries. This report details a study using the benchmarking database, whereby the pattern and sources of productivity changes are investigated using the Data Envelopment Analysis (DEA) method. This is known as the DEA-based Malmquist non-parametric frontier technique.

The study measures productivity changes in the forest harvesting sector in New Zealand. Productivity growth reflects how well an industry has been able to increase its output, while minimising or keeping inputs constant. This consequently increases the competitiveness of the sector. Using the Malmquist Total Factor Productivity (TFP) index that measures productivity (the ratio of output to input), the study shows that productivity growth in New Zealand harvesting was positive, growing at an average rate of 1.7% per annum over the study period.

The index is decomposed into two other productivity change measures, an efficiency change index and a technology change index, in order to better understand the causes of change in relative performance. Efficiency change relates to how well a business or organisation has been able to efficiently manage its inputs to produce outputs. A technology change (or frontier shift) is where the business or organisation has adopted or utilised improved technologies, and therefore the best practice frontier moves upwards.

Productivity is driven by two components; (1) the technology deployed and (2) the efficiency of the technology. The study indicates that the sector experienced productivity growth over the 10-year period primarily as a result of technological progress rather than efficiency growth. The contribution to the overall output (system productivity) growth from technology change ranged from 1.4 to 26%, while that from efficiency gain ranged from 7.3 to 19%. Technological gain was therefore the most important driver of TFP growth in the sector rather than efficiency improvement.

The results of the study show that the productivity growth in the industry was mainly as a result of improved technologies, however, efficiency of the technologies lag. There is potential for increasing efficiency of existing technologies, increasing output while using or reducing current input levels, which should be the focus of the industry in order to achieve sustainable growth in productivity.

INTRODUCTION

The New Zealand forest industry is well-established and has continuously made significant contribution to the growth of the country's economy. In 2018 the forest industry contributed about $3.55 billion to GDP; $1.39 billion from forestry and logging and $2.16 billion from downstream activity (Forest Owners Association, 2019). The vital role of the forestry industry in New Zealand economy is reflected in the strategic role it plays in the government's Regional Growth Programme (RGP) across various regions of the country (MBIE, 2017). The RGP is a key part of the government's economic growth action plan to identify economic challenges and opportunities in different regions of the country, and help attract investments, raise incomes and increase employment opportunities.

With about 1.72 million ha of net stocked plantation forest areas in New Zealand as at 2018, a record harvest volume of 37 million m3 was achieved in 2019 as more trees matured and demand remained high (Forest Owners Association, 2019). The application of biotechnology and genetics in forestry has revolutionized and opened up whole new end use options and demand for planted forest products (Carle and Holmgren, 2008; Hansen, 2016; Pätäri *et al.,*2011). This includes lumber, plywood and veneer, poles, chips, reconstituted panels, modular components (laminated products, moulding, framing, floorings, etc.), pulp and paper, and bioenergy uses. It is predicted that export value from the forestry industry will exceed $7 billion in 2023 with logs accounting for about 44% of total export value (Forest Owners Association, 2019).

The forest harvesting sector of the industry has over the past decade undergone changes in its business environment, including changes in harvesting methods, increased operations on steeper terrain, availability of qualified workforce, and safety and environmental management (Bayne and Parker, 2012; Harrill *et al.,*2019; Kirk *et al.,*1997). In addition, the industry has had to deal with expanding market globalization, the emergence of new competitors and regulatory changes (Fricko *et al.,*2017; Hetemäki and Hurmekoski, 2016; Mayer and Gereffi, 2010). In the face of these changes, industry stakeholders have continued to adapt through investment in technology, training, and development of improved operational guidelines with the aim of remaining locally and globally competitive. However, an important step in industry competitiveness is the continuous measurement and improvement of productivity and management of resources otherwise referred to as benchmarking. This could provide some measurable indices as to the impact of changes within the industry sector on overall productivity over a period of time.

Trends in various production factors of interest within the New Zealand forest harvesting sector are reported annually (Harrill *et al.,*2018; Visser, 2009; Visser, 2016). However, to obtain in-depth information to support macro-decisions by industry stakeholders, it is imperative to deploy effective operations and economic tools to dynamically analyse the efficiency and productivity of the sector. This could provide relevant information required to improve productivity, hence the competitiveness of the sector. Although productivity measurement is not the only determinant of economic growth, it however provides a measure of economic growth and a degree of competitiveness within a production unit (Lall *et al.,*2002). In addition, it provides an indication of the degree of effectiveness of economic policies and, thus, is a useful tool in formulating economic and developmental goals.

The purpose of this study was to apply Data Envelopment Analysis (DEA) based Malmquist Total Factor Productivity (TFP) Index to measure the productivity growth in New Zealand's forest harvesting sector over a 10-year period (2009 – 2018). DEA is a method used in operations research to estimate the relative efficiency of business or organisational units (generally referred to as Decision Making Units, or DMUs), by means of linear programming to identify the best practice frontier within a set of data.

Total Factor Productivity index measures productivity (ratio of output to input) by taking into account all factors of production, as opposed to partial productivity measures in which case single input and output variables are considered. TFP indices are growth indices that reflect global sustainability of an industry (Falavigna *et al.,* 2013). The Malmquist Productivity Index (MPI) is useful in identifying sources of productivity changes. As highlighted in Sowlati and Vahid (2006), productivity growth analysis enables an industry to identify ways of improving its output while keeping input levels constant, thus increasing its competitiveness.

METHODOLOGY

Malmquist Productivity Index

The concept of the Malmquist Productivity Index (MPI), first introduced by Malmquist (1953) and extended by Caves *et al.* (1982a), as an index to measure productivity. The index represents the Total Factor Productivity (TFP) growth of Decision Making Units (DMUs). The TFP index is defined as an index of the ratio of all output produced to all input used in production (Coelli *et al.* 2005). MPI has gained popularity in the measurement of TFP as it does not require price information and allows for further decomposition of TFP growth into changes in efficiency and changes in technology. This decomposition can help identify the sources of changes in productivity and characterize growth patterns (Po-Chi *et al.* 2008). TFP reflects the progress or regress in a DMUs' production or service efficiency and frontier technology between two time periods under multiple inputs and outputs framework (Cooper *et al.* 2007). That is, MPI can be used to evaluate or compare productivity changes of two economies between two time periods. Unlike partial productivity measures (that is, simple output/input ratios), MPI provides an overall measure of productivity (Helvoigt and Adams, 2009).

Färe *et al.* (1992, 1998) showed that the distance functions (the distance of a DMU from the efficient frontier) of the Malmquist Productivity Index can be estimated using DEA, a non-parametric technique. Both parametric and non-parametric methods could be used to estimate the MPI; the major difference being that parametric methods assume an explicit functional relationship between inputs and outputs while non-parametric methods do not require any functional form to relate inputs and outputs (Coelli *et al.* 2005). A key disadvantage of parametric techniques is that the required functional relationship is not always known with certainty (Sowlati and Vahid, 2006) making the non-parametric methods more practicable.

The MPI can be decomposed into two productivity measure components namely, efficiency change index and technology change index, and are computed by means of DEA in a non-parametric framework (Färe *et al.* 1994).

The "efficiency change" component measures the extent to which a DMU (represented in this study by individual forest harvesting operations) has moved toward (or away from) the best practice frontier over time. The improvement over time in the productivity growth of a DMU or a sector could be the result of changes in production or service efficiency over time (catch-up effect or recovery), that is the technical efficiency of the unit increased and therefore it moved closer to the frontier.

The “technology change” component measures the relative change in the best practice frontier over a period of time, and can be interpreted as providing evidence of technological innovation for the sector (Cooper *et al.,* 2007; Sowlati and Vahid, 2006). Technology change (frontier-shift or innovation) is where the DMU has adopted and utilised improved technologies therefore the best practice frontier moved upwards. The term technology as used here has a broader meaning and includes production technologies, machinery, policies, regulations and the business environment that affect the productivity of a DMU within an industry.

A DMU is said to operate under Constant Returns to Scale (CRS) when a proportional increase in its inputs results in the same proportional increase in the outputs. Whereas when a proportional increase in the inputs results in more (or less) than the proportional increase in outputs then the DMU is said to operate under Variable Returns to Scale (VRS).

Efficiency change, under VRS can be decomposed into pure technical efficiency change and scale efficiency change. Pure technical efficiency change is the efficiency change calculated under variable returns to scale technology (Färe *et al.,*1994).

The scale efficiency change estimates the deviation between CRS technology and VRS technology allowing to further determine the sources of inefficiency (Banker, 1984; Mao and Koo, 1997). Scale efficiency changes correspond to movements along the frontier toward a technically optimal scale. That is, progress in scale efficiency change for a DMU means that it has moved to a position of better input-output quantity ratio at the frontier (Balk, 2001). The procedure for estimating the Malmquist Productivity Index and its component indices is well detailed in the literature (Caves *et al.,*1982b; Färe *et al.,*1994; Mao and Koo, 1997).

In interpreting the indices of efficiency change and technology change, an index with a value greater than 1.0 indicates growth, and a value less than 1.0 indicates decline. Similarly, for the MPI, a value more than 1.0 indicates that progress or growth has occurred in TFP, while a value less than 1.0 represents a decline or regress. However, a value of 1.0 for the indices denotes that no change has occurred in the productivity index.

Data Envelopment Analysis

Data Envelopment Analysis is a non-parametric method (one where the data are not expected to fit a normal distribution) that can be used to estimate the relative efficiency of DMUs by means of linear programming to identify the best practice frontier within a set of data. In contrast to parametric techniques such as the stochastic frontier analysis (SFA) that applies an assumed structure to fit the observed data, DEA is distribution free and allows the data to speak for themselves (Ma and Feng, 2013). Charnes *et al*. (1978) first introduced the CCR model of DEA that estimates the relative efficiency score of production units by means of linear programming under constant returns to scale (CRS), and Banker *et al.* (1984) introduced the BCC DEA model applicable to technologies under variable returns to scale (VRS). The names of these models derived from the initials of the authors of the models. The major difference between the two DEA models is that CCR model is unable to distinguish inefficiencies attributable to scale and technical inefficiencies in the final efficiency results while the BCC model can by estimating pure technical efficiency at the given scale of operations.

The non-parametric DEA model in addition to other parametric techniques such as stochastic frontier analysis can be used to solve the distance functions for the MPI. Since the non-parametric DEA is adequate for solving the productivity distance functions (Armagan *et al.,* 2010; Li and Liu, 2010), the technique is applied in this study.

Inputs and Outputs

This study utilises data in the Harvesting Cost and Productivity Benchmarking database developed by Forest Growers Research Ltd., or FGR, (formerly Future Forests Research Ltd.) and managed by the University of Canterbury, New Zealand (Visser, 2009). This database contains system, stand and terrain factors at the harvest area level for harvesting operations undertaken in New Zealand from 2008 to 2018. An important unique factor of the database is that it contains data on individual forest harvesting operations thus providing higher variability, unlike aggregated data with reduced variability and potentially lower efficiency frontier (Helvoigt and Adams, 2009).

The data were screened to remove entries with missing or invalid data and outliers. Panel data for the year-to-year analysis were obtained from the database comprising 73 DMUs (individual forest operations) over a period of 10 years from 2009 – 2018. This resulted in a total of 730 entries of individual forest harvesting operations. These data were used to represent a subset of the entire database that has over 1500 data entries (Visser, 2019). Five inputs and one output were specified for estimating the productivity measures of the forest harvesting sector. They were number of workers, number of machines, average scheduled work hours per day, harvest area size, average piece size and system productivity. Table 1 presents a description of the inputs and output used in this study.

Table 1. Input and output variables

Variable	Description
Inputs	
Number of workers (NWork)	Average number of harvest crew members for the duration of the harvest operation.
Number of machines (NMach)	Total number of machines deployed on site for a specified harvest operation.
Scheduled work hours per day (AvSWk)	Average number of scheduled work hour per day in hr.
Harvest area size (HarAS)	Size of a single contiguous harvest area in ha.
Average piece size (AvPiS)	Average piece (tree) size from the harvest area in ton/stem.
Output	
System productivity (SysPro)	Productivity of the harvest system deployed calculated as the total volume of timber harvested divided by the total harvest time.

RESULTS

Trends in production factors

Figure 1 shows the yearly trend for the means of the various inputs and output over a 10-year period. The figure shows that over the period 2009 - 2018, trends in the average piece size (AvPiS) and average scheduled work hours per day (AvSWk) were both generally flat. However, depending on the silvicultural regime adopted, the average piece size ranged from 1.6 to 2.3 m^3 (Harrill et al., 2019). Average number of workers (NWork) for individual forest harvesting operations has been in decline from 8.4 in 2009 to 6.3 in 2018. The number of machines (NMach), harvest area size (HarAS) and system productivity (SysPro) have all been generally in upward trend.

The combined declining trend in the number of workers and the upward trend in the number of machines within the forest harvesting sector in New Zealand suggests an increasing level of mechanisation. This increase in mechanisation is expected to be sustained into the future as new technologies are being developed and deployed towards robotisation of forest harvesting operations (Milne *et al.*, 2013; Visser, 2018).

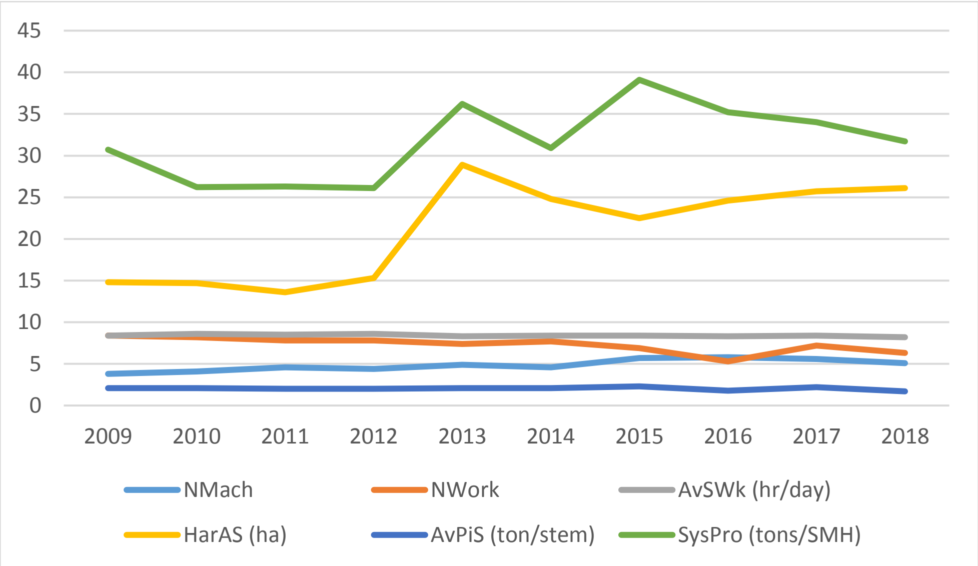

Figure 1. Trends in mean production factors over the 10-year period

Although system productivity has generally been increasing over the years (especially between 2012 and 2015), it experienced consistent decline from 35.2 tonnes/SMH in 2016 to 31.7 tonnes/SMH in 2018. The estimated MPI could provide the underlying reason for the decline in system productivity over this 2-year period, that is, the direction of efficiency change and technology change. A similar trend was reported by Harrill *et al*. (2019) for average harvesting productivity by system type – ground-based versus cable systems – for the period 2009 – 2017. Forest harvesting operations in New Zealand have in recent times been moving on to more steeper terrain which could explain the recent decline in system productivity as it is more challenging and generally less productive on which to operate than flat terrain (Obi and Visser, 2017; Raymond, 2012; Visser et al., 2014).

Malmquist Productivity Index (MPI) and its decomposition

The productivity change in New Zealand forest harvesting sector was measured using the DEA-based MPI. A DEA model with five inputs and one output was used to estimate the required distance functions. The DEA software package, DEAP version 2.1 by Coelli (1996) was used to estimate the MPI. The MPI then was decomposed into efficiency change index (catch-up effect) and technology change index (frontier shift) to identify the sources of the productivity changes.

Table 2 presents the estimated productivity measures for the entire New Zealand forest harvesting sector for the period 2009 - 2018.

On average, productivity of the New Zealand forest harvesting sector as a whole grew by a rate of 1.7% per annum over the past 10 years (mean MPI = 1.017). The progress in overall productivity could mean that either the sector improved its technological innovations during the period under consideration, or changed its practices to have resulted in improved efficiency, or both.

Overall efficiency (proximity to the production frontier) declined on the average by 1.1% per annum in the 10-year period (mean = 0.989). The contribution from efficiency gain to the overall productivity progress ranged between 7.3% in 2010-2011 to 19.2% (in 2012-2013).

Technology progress (the outward movement of the production frontier) for the sector improved by 2.8% per annum (mean = 1.028). The contribution to overall productivity growth from technology change ranged between 1.4% in 2010-2011 and 25.6% (in 2015-2016).

This productivity growth could be attributed mainly to innovations in forest harvesting technologies, however efficiencies of the technologies are yet to be fully maximised.

Table 2. Productivity measure and its components in New Zealand's forest harvesting sector (2009 - 2018)

Period (Years)	Productivity measure				
	Efficiency change (catch-up effect)	Technology change (frontier shift)	Pure efficiency change	Scale efficiency change	Malmquist Productivity Index
2009 - 2010	0.917	0.921	0.997	0.920	0.845
2010 - 2011	1.073	1.014	0.987	1.087	1.088
2011 - 2012	0.944	0.993	1.005	0.939	0.938
2012 - 2013	1.192	1.072	1.032	1.155	1.278
2013 - 2014	0.911	0.979	0.953	0.956	0.892
2014 - 2015	1.105	1.094	1.031	1.072	1.210
2015 - 2016	0.825	1.256	0.854	0.966	1.036
2016 - 2017	1.113	0.788	1.19	0.935	0.877
2017 - 2018	0.882	1.222	0.841	1.049	1.078
Mean	**0.989**	**1.028**	**0.983**	**1.006**	**1.017**

To further understand the underlying factors driving the overall decline in efficiency change index, it is decomposed into pure technical efficiency change and scale efficiency change (Table 2). Overall for the sector in the period 2009 – 2018, the scale efficiency change improved marginally by 0.6% (mean index = 1.006) while the pure technical efficiency declined by 1.7% (mean index = 0.983). This suggests that the overall decline in catch-up effect for the sector could be attributed largely to regress in pure technical efficiency.

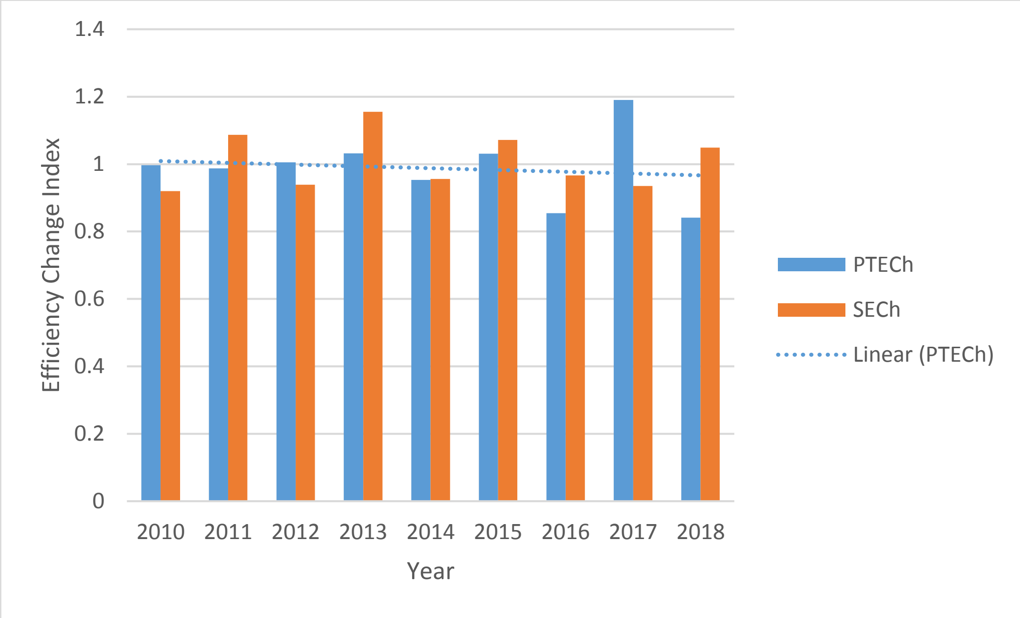

Figure 2. Pure technical efficiency change (PTECh) and scale efficiency change (SECh) over the 10-year period

Figure 2 shows a plot of the pure technical efficiency change (PTECh) and scale efficiency change (SECh) against time (year) showing patterns of change in the indices. The indices fluctuated and the gains were not sustained across the years as they moved up (growth) and down (decline). In addition, a linear trend line suggests an overall decline in pure technical efficiency.

DISCUSSION

The growth in technology change could be attributed to the series of industry initiatives aimed at improving productivity and safety within the sector. Such initiatives include the Steep Land Harvesting Primary Growth Partnership (PGP) funded by Forest Growers Research Ltd. (formerly Future Forests Research Ltd.) and the government. Future Forests Research was formed in 2007 and under its current name, Forest Growers Research, funds forest growing and harvesting research through the Forest Growers Levy Trust, which represents the largest forest industry funder of research and development in New Zealand (FGR, 2019). These programmes have been led by a partnership of forestry companies, harvesting and logistics contractors, and machinery manufacturing firms. This research aims to create value, improve profitability, and enhance sustainability across the forestry value chain (FGR, 2017; Todd, 2016).

While the growth in total factor productivity was mainly influenced by the technology change, the index fluctuated and was unstable across the years as it went up (growth) and down (decline). Hence, the introduction and adoption of innovative forest harvesting technologies should be enhanced.

The average decline in efficiency change, which measures the dispersion of forest harvesting operations with reference to the best production frontier, suggests underutilization of inputs. In other words, technology in New Zealand's forest harvesting sector has continued to improve, whereas optimum utilisation of the technologies has lagged the technology frontier.

Figure 3. Winch assist machines: a good example of innovation in technology, but overall utilisation has remained relatively low.

Although Di Fulvio *et al.* (2017) reported a general increase in utilisation rate following the introduction of newer technologies, this is not always the case. In New Zealand, for example, the introduction of winch-assist machines for feller bunchers on steep slopes (Figure 3) has increased harvesting productivity, but overall utilisation has remained relatively low. Harrill *et al.* (2018) reported an average utilization rate of 45% following the introduction of winch-assist machines. In more recent case studies that figure has climbed to just over 60% (Leslie 2019), but overall is still low for a high cost system.

The highest annual productivity growth of 27.8% (MPI = 1.278 in Table 2) for the sector within the time period under review was recorded in the period 2012 – 2013. This was the result of growth in efficiency change and technology change of 19.2% and 7.2%, respectively. This could be linked to the period of increased innovation and mechanisation of harvest operations in New Zealand stimulated by the Steep Land Harvesting PGP, as well as the accelerated growth in harvest volume from 2010 to 2013 in response to increased demand as shown in Figure 4.

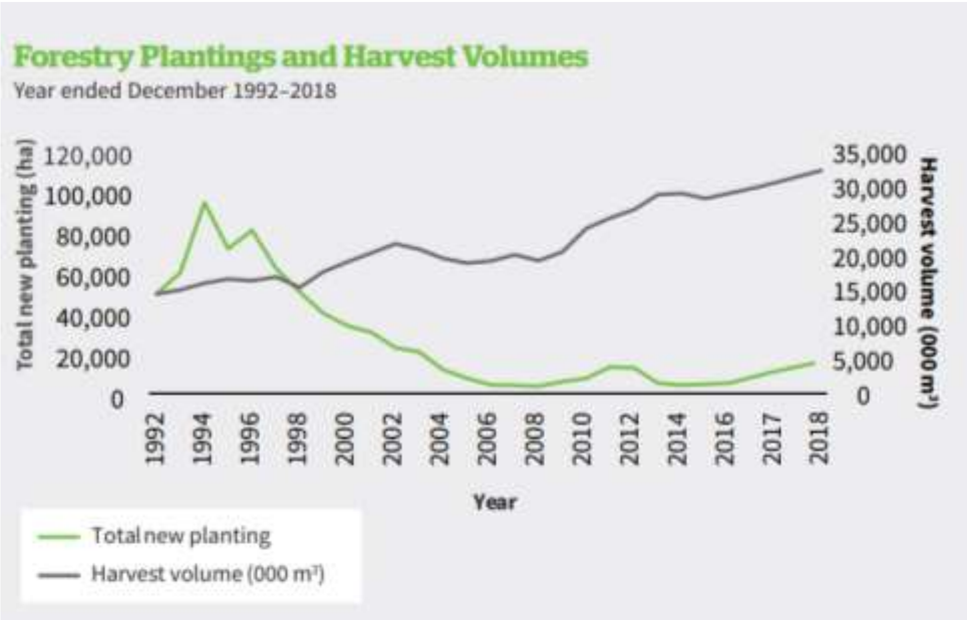

Figure 4: Year-on-year harvesting volumes (Forest Owners Association, 2019)

Technological innovation in the New Zealand forest harvesting sector could be attributed to demand/market-pull, otherwise referred to as demand-led innovation. That is, innovation that derives in response to user/consumer needs, as expressed through market demand or other channels (Cox and Rigby, 2013; Knell, 2012). A similar trend occurred in the white water kayaking industry where 87% of all significant innovations in the industry have been demand-led (Hienerth et al., 2014). In addition, Chancellor et al. (2015) reported that the increase in demand for heavy civil engineering construction across some states in Australia was responsible for the productivity growth the Australian construction industry witnessed from 2002 to 2010.

One of the goals of the Steep Land Harvesting PGP initiative was to improve harvesting productivity through the development and commercialisation of modern steep land harvesting technologies; this is estimated to have improved by up to 30% (FGR, 2018a). The highest decline in the MPI was recorded for the sector in the period 2009 – 2010 with a decline of 15.5% (MPI= 0.845). This was through a decline in both efficiency change (-8.3%) and technology change (-7.9%). This is not unexpected, considering that this period coincided with the period of the lowest mechanisation level for the sector recorded over the 10-year period.

Sources of productivity changes

The results presented in Table 2 suggest that the growth recorded in New Zealand forest harvesting sector has been largely supported by growth in technology change (frontier shift), that is, technological innovation.

A mechanisation index for the sector was calculated as the ratio of the average number of machines to average number of workers in each harvesting crew. A plot of this average mechanisation index for the sector for the period 2009 – 2018 is given in Figure 5. This shows that the sector witnessed an upward trend in its mechanisation level for the past 10 years, except in 2017 when the mechanisation index dropped from 1.12 in 2016 to 0.78. This drop in mechanisation level was reflected in the frontier shift for the period 2016 – 2017 when it declined by 21.2% (technology change index = 0.788).

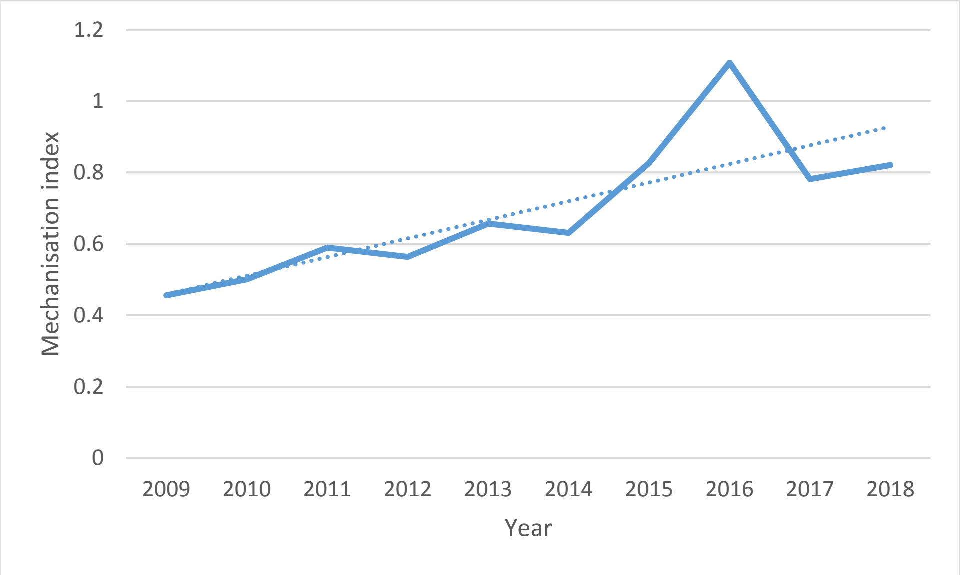

Figure 5. Trend in mechanisation level of New Zealand forest harvesting sector

The introduction of winch-assist machines in New Zealand forest harvesting operations, as well as other innovations over the past 10 years, has no doubt played a significant role in the growing mechanisation level of the sector (especially in cable logging operations). Winch-assist extends the safe operating limits of ground-based felling machines on significantly steeper terrain that was previously inaccessible by unassisted machines (Amishev, 2012; Visser and Berkett, 2015; Visser and Harrill, 2017). This has increased mechanisation of tree felling in cable-based operations by decreasing motor-manual felling and, through ability to bunch felled stems, has encouraged the use of grapples in place of manual choker-setters (breaker outs) during log extraction (Harrill *et al.,* 2018).

From 2009 to 2018, the proportion of all harvesting operations using mechanised tree felling for the sector (both ground-based and cable operations), increased from 23% to 62%. It is evident that the sector needs to continue to invest more in mechanising its operations with the aim of automating some functions. However, for the sector to achieve sustainable productivity growth, it needs to match the growing technological innovations with improved production efficiency from these innovations.

The efficiency change for the sector as a whole was the only productivity index that was in decline (by 1.1% for the 10-year period under consideration). The decline in efficiency indicated that the distance of the production units to the efficient frontier was growing, suggesting that the full potential of current harvesting technologies may not have been fully exploited.

The current New Zealand forest harvesting sector productivity scenario is similar to the total factor productivity of China's agricultural sector between 1990–2004. Following China's government investments in infrastructure accompanied by high demand for agricultural commodities, the sector experienced consistent TFP growth for decades driven by technological progress, but efficiency change remained stagnated (Jin et al., 2010; Ma and Feng, 2013).

The overall decline in catch-up effect (efficiency change) in the New Zealand forest harvesting sector suggests that harvesting operators could be utilising more inputs than necessary to achieve the current system productivity level. At the micro-level of individual forest harvesting operations, decline in efficiency could be an input misallocation problem which could be improved through reallocation of input resources for optimum utilisation. In as much as the future of forest harvesting operations lies in automation of processes, attention must be given to the optimum or efficient utilisation of input resources including equipment and machinery.

Recent research and development programmes on steep terrain harvesting in New Zealand may have improved harvesting economics and contributed to the increase in production output (FGR, 2017; Raymond, 2012). However, improvement in production efficiency of the harvesting technologies may require more attention - this relates to the minimisation of inputs relative to unit outputs. The challenge with the current situation is that continued deterioration in efficiency change could in the long term reduce the marginal benefits of research and investments in technological progress thus rendering the current productivity growth unsustainable.

It is important to note that although efficiency change and technology change are decomposed components of MPI, their influence on productivity gains are distinct, as such different policies and strategies may be required to address them (Po-Chi *et al.*, 2008). While technical progress is linked to the adoption and utilization of improved technologies to advance productivity through gains in outputs, efficiency progress could bring about productivity growth without the adoption of new or more productive technologies (Balk, 2001). In achieving sustainable productivity growth, deliberate effort needs to be in place to bring about progress in both efficiency change and technology change. Theoretically, a lower efficiency level signifies some level of potential to raise productivity through improved technical efficiency (Ma and Feng, 2013). Therefore, declining efficiency change in New Zealand's forest harvesting sector is an indication that there is room for efficiency improvement by means of optimum utilisation of input resources which will ultimately improve TFP.

The decline in pure technical efficiency further supports the view that the industry needs to focus more on improving the efficient use of its input resources with respect to its current harvesting technologies while continuing to mechanise its operations for sustained industry TFP growth. Winch-assist (tethered) felling machines (a major technological development in New Zealand forest industry) for example, has continued to complement cable yarding systems by improving safety and increased mechanisation of felling, however the full potential of winch-assist has not yet been explored in terms of efficiency and cost effectiveness (Visser and Harrill, 2017).

CONCLUSION

This study applied the DEA-Malmquist productivity index to the New Zealand forest harvesting sector and provided empirical data regarding the productivity of the sector over the period from 2009 – 2018. The results indicated that Total Factor Productivity grew at a rate of 1.7% over the entire 10-year period, with technological innovation playing a key role in the gain. The pattern of efficiency change, technology change and productivity changes in the sector for the period 2009 – 2018 suggests that technological progress has been driving productivity in the sector while operational efficiency has been lagging.

It is laudable that the forest industry and the New Zealand government have partnered in a further programme of initiatives to develop and implement innovative technologies with the goal of automating all forest harvesting operations (FGR, 2018b). However, more efforts need to be directed at improving the production efficiency of existing technologies. Without using the existing technologies to their full potential, declining efficiency could continue to drag potential productivity in the sector. While increased mechanisation and a move to more automation may provide improved safety and worker satisfaction, and increase total productivity (Passicot and Murphy, 2013), this may not necessarily translate into operationally efficient systems.

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