ACIAR PROJECT FST/2019/128

Financial and Economic Modelling Report 7:

Queensland Application of the Mill-Gate to Manufactured EWP Module of the Mathematical Programming Model to Support Engineered Wood Product Manufacturing Decisions

Coconut and other non-traditional forest resources for the manufacture of Engineered Wood Products (EWP)

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August 2023

Queensland Application of the Mill-Gate to Manufactured EWP Module of the Mathematical Programming Model to Support Engineered Wood Product Manufacturing Decisions

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Executive Summary

Financial information to support engineered wood product (EWP) manufacturing investment decisions in Fiji is limited, particularly with coconut. It is critical that financial evaluations of investment opportunities accompany research activities that assess resource availability, technical aspects of EWP processing and potential markets. This project report summarises progress made on a mathematical model in R software that can support EWP manufacturing decisions in Fiji. The analyses presented within this paper were completed as part of a financial evaluation of laminated veneer lumber (LVL) and finger-jointed LVL manufacture for the Robertson Brothers sawmill, a project partner located in Gympie, Queensland. This paper reports the financial performance of twelve one-stage, two-stage and finger-jointed LVL products under four log procurement scenarios and two log processing scales (10,000 m^3/y and 15,000 m^3/y), as requested by the Robertson Brothers. The four log procurement scenarios were evaluated using average mill-delivered log costs (MDLC) per cubic metre provided by the Robertson Brothers. These scenarios included: (i) 100% compulsory logs, (ii) 100% optional logs, (iii) 100% salvage logs, and (iv) their existing log intake of the three log types.

Average profit and costs (\$/m^3) was estimated for each of the 12 final products. The analyses found that profit was greatest when compulsory logs were utilised due to their large diameter and low levels of sweep and taper which generated the highest recovery among all log types . Under all final products and log processing scales, utilising 100% compulsory logs maximised profits, whilst 100% salvage logs was the least profitable log procurement strategy for all final products. The Robertson Brothers current mix of logs, which contain 62% compulsory logs, was the second-best log procurement scenario. Increasing the log processing scale from 10,000 m^3/y to 15,000 m^3/y increased profit under all scenarios. Market price was the largest contributor to a product's financial performance with the five highest priced products also being the five most profitable. Upgrading products through value-adding was found to increase profitability.

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1. Introduction

The aim of the broader ACIAR project is to deliver and validate wood processing technologies to transform coconut and other currently low-value forest resources in Fiji into high-value engineered wood products (EWPs) suitable for local and international markets. Financial information to support EWP manufacturing investment decisions in Fiji is scarce, and a financial evaluation of investment opportunities is a critical complementary research activity to accompany assessments of resource availability, technical aspects of EWP processing and potential markets.

The overall objective of the economic research in FST/2019/128 is to develop a mathematical programming model to support decision-making with respect to investments in EWP manufacture with coconut and other in Fiji. The objective function of the model is to maximise the net present value (NPV) of investment in EWP manufacture. The decision variables that the model optimises to maximise NPV will provide valuable information to potential investors, including:

- which forest resources should be harvested (*e.g*. coconuts and mahogany) and from where on the landscape?;
- where there is variation in log size and quality, which log types should be procured from the forest resources (*e.g*., small diameter versus large diameter logs, and short length versus longer logs)?;
- where to establish EWP manufacturing facilities?;
- should veneering and EWP manufacture should occur at the same location or should veneering should be performed closer to the resource in a decentralised business model?;
- what is the economically efficient scale of operation (log volume, labour and equipment)?; and
- which final products should be produced?

The purpose of this milestone report is to summarise progress on the 'mill gate to manufactured EWP' module of the mathematical model. This module accounts for the:

- recoveries of veneer from log volume of different log types;
- recoveries of marketable product from veneer volume (e.g., due to degrade, docking to product dimensions and dressing);
- processing rates of veneer and EWPs (e.g., log volume processed per hour);
- utilisation rates of equipment (e.g., fraction of the work year the kiln drier will dry veneer);
- capital cost requirements at each processing stage;
- labour and other variable and fixed costs of manufacturing veneer and EWPs; and
- market prices of EWPs.

To demonstrate progress on this module, the Robertson Brothers sawmill located in Gympie, Queensland, was selected as the case study for this report. The Robertson Brothers primarily manufacture sawn wood products but have expressed interest in investing in veneer and laminated veneer lumber (LVL) manufacture. This paper reports the financial performance of various one-stage, two-stage and finger-jointed LVL products under several log procurement scenarios and log processing scales requested by the Robertson Brothers.

Conducting this case study provided the authors the opportunity to ensure that the relationships between various components of the mill-gate to manufactured EWP module were working as expected and also accommodate finger-jointing into the model. The next milestone report, due in February 2024, will apply the mill to market module to Fiji with Fiji-specific data.

2. Research Method

The mathematical programming model that has been developed in R software to evaluate the financial performance of investments in EWP manufacture in Australia and Fiji (Venn et al., 2022) has been parameterised to evaluate the financial performance of LVL manufacture for the Robertson Brothers. The Robertson Brothers indicated using the model to generate optimal EWP scenarios, as has been described in previous milestone reports, would not be needed because they: (i) already have a good understanding of where to harvest logs on the landscape and the associated harvest and haul costs; and (ii) requested an assessment of several final products separately, rather than an investigation of optimal mixes of products. As such, the mathematical model described in this paper has been run separately for specific combinations of log procurement, processing scale and final product scenarios that are of interest to the Robertson Brothers.

The costs and profits per cubic metre of final product, and the net present value (NPV) of all EWP manufacturing scenarios were evaluated for a 30-year project life. Estimates of costs and profits per cubic metre do not account for the time value of money, because discounted profit margins are not useful for decision-making by the wood products industry. A 7% real (net of inflation) discount rate has been applied to calculate the NVP. Further detail on these financial methods can be found in Venn *et al*. (2021). To evaluate differences in the financial performance of various log procurement scenarios, the analysis utilised an average mill-delivered log cost ($/m^3 of log) for each of the log types analysed, which were provided by the Robertson Brothers. A sensitivity analysis was carried out on the mill-delivered log costs where the base case parameter levels were increased and decreased by 10% and 30%, and the results of the sensitivity analyses are reported in the Appendix. The sensitivity analyses performed represent the method in which sensitivity analyses can be performed by the model.

3. Processing scenarios and parameters for the Robertson Brothers case study

Ninety-six LVL manufacturing scenarios have been examined to demonstrate the ‘mill-gate to EWP’ module, consisting of four log procurement scenarios, two log processing scales, and twelve final product scenarios which include a range of one-stage LVL, two-stage LVL and finger-jointed LVL products. The two annual log processing scales evaluated were 10,000 m^3/y and 15,000 m^3/y.

3.1 Log procurement scenarios

Four hardwood log type scenarios have been examined, namely compulsory sawlogs only, optional sawlogs only, salvage logs only and the existing mix of these log types utilised by the Robertson Brothers. Table 1 outlines the proportion of logs by small-end diameter under bark (SEDUB) for each log type in the

Robertson Brothers’ operation from July 2021 to April 2022. These proportions have been assumed for all log type scenarios.

In previous research, the authors had adopted log type classifications based on log small-end diameter. However, Robertson Brothers provided the research team with historic log procurement data that used the Queensland Department of Agriculture and Fisheries log classification of compulsory, optional and salvage logs (Queensland Department of Primary Industries-Forestry 2001). Compulsory logs are relatively straight and cylindrical, and have low levels of defect, while the lower quality optional and salvage logs have log geometry or defects that will reduce the recovery of wood products. Compulsory, optional and salvage logs can have a similar range of small-end diameter classes, although the historic data from the Robertson Brothers suggest mean log diameters tend to be smaller for lower quality logs (Table 1).

Table 2 reports the log geometry specifications adopted by log type. In this analysis, log taper was set to 0.0075 m/m for all logs, which was the average for small diameter *Eucalyptus* and *Corymbia* native forest and plantation logs processed in recent veneering studies (McGavin et al. 2014a; McGavin and Leggate 2019). A preliminary attempt to capture the lower green veneer recovery from lower quality log classes focussed on assumed levels of log sweep as a proxy to capture recovery losses from both log geometry and log defects. The mean SEDUB for all log types procured by the Robertson Brothers was between 31 cm and 40 cm (Table 2) and the log grading rules for logs from public lands in Queensland (Queensland Department of Primary Industries-Forestry 2001) allow up to a maximum of 2.5 degrees bend in a compulsory log with a centre diameter of up to 40 cm[1]. That is equivalent to 0.0436 m/m sweep (shift of the centre line of the tree). For the purposes of analysis, compulsory logs are assumed to have zero sweep, optional logs are assumed to have 0.0218 m/m sweep and salvage logs are assumed to have 0.0436 m/m sweep. The Robertson Brothers indicated that a billet length of 3.3 m was appropriate for this analysis, which is longer than the 2.6 m length assumed in previous milestone reports. Recoveries of green veneer from log volume are sensitive to these log geometry assumptions and further work is justified to evaluate whether the levels adopted are appropriate.

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[1] Given the billet length of 3.3 m and log taper of 0.0075 m/m used in this analysis, a log with a small-end diameter of 40 cm will have a centre diameter of 1.65 x 0.0075 = 41.2 cm.

Table 1. Distribution of SEDUBs by log type

SEDUB (cm)	Distribution of log sizes by log type (%)		
	Compulsory sawlog	Optional sawlog	Salvage log
22	0.0	0.0	0.1
24	0.0	0.0	1.0
26	0.0	0.3	6.6
28	0.0	4.2	25.8
30	0.6	17.0	30.7
32	4.8	19.5	16.4
34	16.2	11.6	6.2
36	16.7	14.3	4.6
38	15.4	7.6	2.8
40	10.2	5.7	1.5
42	7.3	4.7	1.2
44	6.6	4.1	0.4
46	4.2	2.2	0.4
48	3.9	1.7	0.7
50	1.9	1.6	0.4
52	1.9	0.8	0.3
54	1.6	0.6	0.1
56	1.4	0.9	0.1
58	1.2	0.5	0.1
60+	6.1	2.7	0.6
Total	100.0	100.0	100.0

Table 2. Log geometry specifications, MDLCs and current mix of log types

Log specification	Log type		
	Compulsory sawlog	Optional sawlog	Salvage log
Billet length (m)	3.3	3.3	3.3
Sweep (m/m)	0	0.0218	0.04364
Taper (m/m)	0.0075	0.0075	0.0075
Mean SEDUB (cm)	40.87	36.39	31.19
MDLC ($/m^3)	250	190	125
Green veneer recovery from log volume (%)	93	63.3	28.7
Proportion of log type within current operation (%)	61.63	21.52	16.85

The Robertson Brothers provided the average mill-delivered log cost (MDLC) for each log type reported in Table 2. The green veneer recovery rates from log volume were determined from equations developed by Venn *et al*. (2021), which account for waste due to log rounding and the peeler core. A cylindrical peeler core with a diameter of 45 mm and volume of 1.59×10^{-3} m^3/m of log length has been modelled. The green veneer recovery rates were based on the distribution of log diameters in Table 1, and the log geometries outlined in Table 2.

The Robertson Brothers are particularly interested in evaluating the financial performance of manufacturing LVL products using their current intake of logs. The proportion of each log type utilised in their existing production was provided to the authors and is outlined in Table 2. Based on the MDLCs in Table 2 and the composition of log types within their current production, the average MDLC for their current operation was estimated to be \$213/m^3 of log.

3.2 Final product scenarios

Twelve final product scenarios have been assessed which include a suite of one-stage LVL; two-stage LVL and finger-jointed LVL products. The dimensions and market prices of these products were provided by the Robertson Brothers and are indicated in Table 3. Table 3 also identifies which LVL products are used as feedstock for each finger-jointed product.

3.3 The modelled manufacturing process

The production process for each final product is outlined in Figure 1. Hardwood logs delivered to the processing facility are pre-conditioned (heated) prior to being docked to 3.3 m length billets. Billets are then fed into a rounding-debarker lathe to produce a cylindrical billet prior to veneering. Next, the billets are processed through a spindleless lathe, and green veneer ribbons are recovered until the residual cylindrical peeler core at the centre of the billet is reached. The green veneer ribbons are clipped to the desired length and proceed on-site to a drying facility. Green veneer sheets are dried in a conventional jet-box dryer to a moisture content of approximately 5% and clipped to remove damage that may have occurred during the drying process.

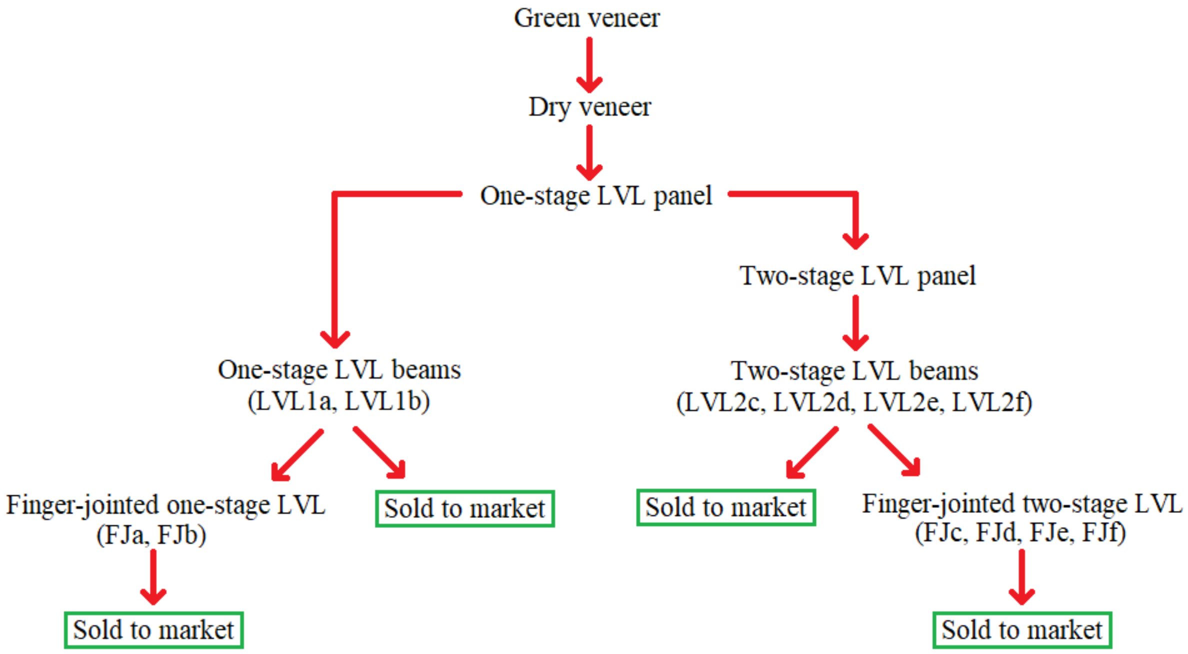


Figure 1. The production process of one-stage LVL, two-stage LVL and finger-jointed LVL

Table 3. Final product dimensions, prices and finger-joint feedstock products

Product	Process stage	Length (mm)	Width (mm)	Thickness (mm)	Price ($/m^3 of final product)	Finger-joint feedstock
Green veneer	Green veneer	3250	1400	3.2	-	
Dry veneer	Dry veneer	3150	1270	3	-	
LVL1 panel	One-stage LVL	3100	1200	38	-	
LVL1a		3100	100	38	1300	
LVL1b		3100	75	38	1300	
LVL2c	Two-stage LVL	3100	250	75	2100	
LVL2d		3100	150	50	1500	
LVL2e		3100	200	75	1900	
LVL2f		3100	150	75	1650	
FJa	One-stage LVL finger-jointing	6000	100	38	1500	LVL1a
FJb		6000	75	38	1500	LVL1b
FJc	Two-stage LVL finger-jointing	6000	250	75	2400	LVL2c
FJd		6000	150	50	1750	LVL2d
FJe		6000	200	75	2200	LVL2e
FJf		6000	150	75	1950	LVL2f

Note: The letter following each “FJ” product denotes the one-stage or two-stage LVL product that supplies feedstock to the FJ product. For example, LVL1a is used for feedstock for the manufacture of FJa, and LVL2f is the feedstock for FJf

All the dry veneer produced is utilised for the manufacture of one-stage LVL panels. One-stage LVL manufacture has been modelled assuming traditional plywood production equipment is utilised. This restricts LVL section length to billet length (3.3 m), less necessary end-trimming. One-stage LVL panels are produced by gluing together dry veneer sheets with a phenol formaldehyde-based glue (PF), then pressed in a cold press for 6 min before being placed in a hot press for 20 min to cure the adhesive. One-stage LVL panels can either be glued together to produce two-stage LVL panels, or sawn into one-stage LVL beams.

If two-stage LVL panels are produced, a number of one-stage LVL panels are glued together in a cold press for 8 h with a resorcinol formaldehyde-based glue (RF) and sawn into boards to form a larger dimension product that cannot be manufactured in a conventional one-stage process. Depending on the final product scenario, one-stage and two-stage LVL beams are either sold to market or processed into finger-jointed LVL. If finger-jointed LVL is produced, one-stage or two-stage LVL sawn beams are loaded into the finger-jointer machine which glues the beams together longitudinally to produce 6100 mm finger-jointed LVL boards that are then docked at either end to produce a 6000 mm uniform beam. All finger-jointed products are sold to market.

3.4 Recovery of final products

The analysis assumes that 75% of the green veneer produced is recovered as dry, graded veneer. This is based on empirical studies by McGavin et al. (2014a); McGavin et al. (2014b) and McGavin and Leggate (2019), who found that approximately 75% of green veneer from *Eucalyptus* and *Corymbia* logs is recovered as dry, graded veneer. The volume loss from green veneer is due to defects in the veneer sheets (from imperfections inside the log), trimming veneer to marketable dimensions, and shrinkage during drying. Since the one-stage and two-stage LVL beams are sawn from one-stage and two-stage LVL panels, respectively, the dimensions of the panel and the beams being sawn influence the recovery of beams from the panel. This is because the number of LVL beams that can be sawn from an LVL panel is limited by the widths of the LVL panel and the LVL beams being cut from the panel, as shown in Figure 2. LVL products that can better utilise the entire LVL panel offer higher recovery rates than LVL products which leave a high volume of panel waste. The equations to estimate the recovery of one-stage and two-stage LVL have been previously published in Venn *et al*. (2021).

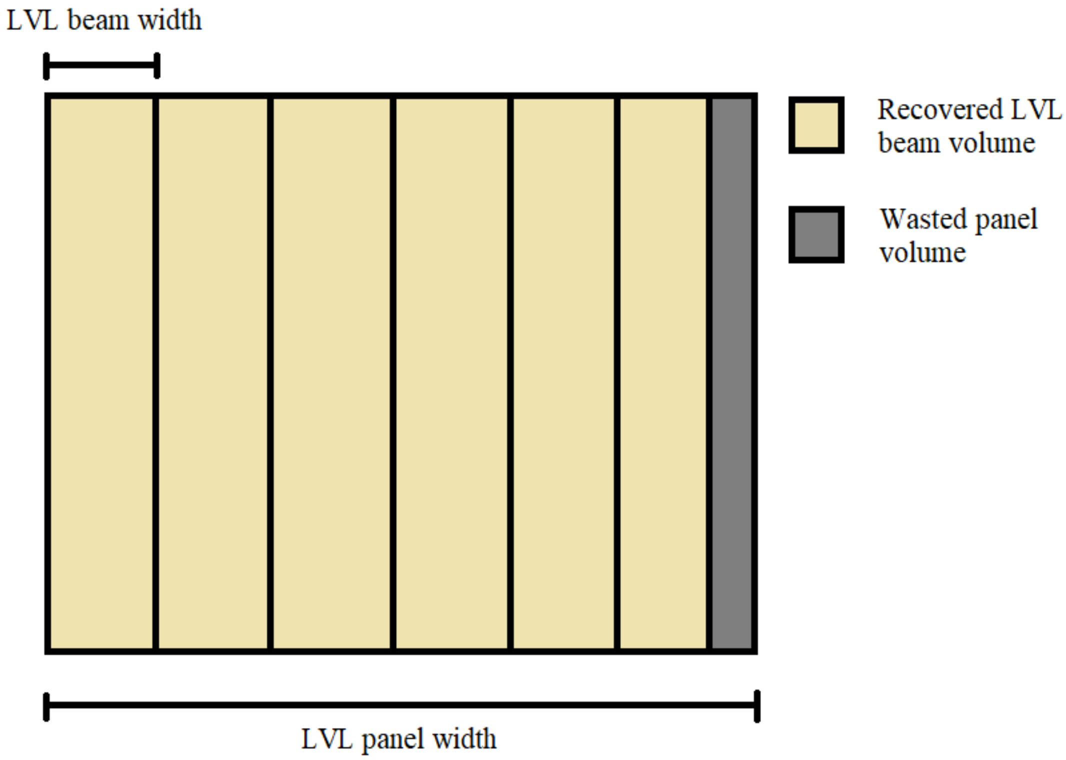


Figure 2. Example of the recovery of an LVL beam from an LVL panel

The losses that are incurred during finger-jointing include the loss of length from cutting the finger-joints and the docking of the finger-jointed LVL board from 6100 mm to a final length of 6000 mm. Equations 1 and 2 define the equations used by the model to determine the recovery of finger-jointed LVL from log volume. Table 4 describes each of the variables in Equations 1 and 2 and the parameter value of each of the variables used in the analysis. Variables with no defined value in Table 4 represent derived variables whose values are determined from Equations 1 and 2.

$$FJRecovery = \frac{FinalFJProductLength}{PreDockLength + FingerLength * JointsInBoard + SawKerf} \quad \text{[eq. 1]}$$

$$JointsInBoard = \frac{PreDockLength}{FeedstockLength} \quad \text{[eq. 2]}$$

Table 4. Variables in Equations 1 and 2 and the values adopted in the analysis

Variable name	Description	Value used in analysis
$FJRecovery$	Recovery of finger-jointed LVL from log volume (%)	-
$FinalFJProductLength$	Final finger-jointed LVL length (mm)	6000
$PreDockLength$	Length of the finger-jointed LVL prior to docking (mm)	6100
$FingerLength$	Length of the fingers used in the finger-jointing (mm)	20
$JointsInBoard$	Number of finger-joints in a pre-docked finger-joint board	1.97
$SawKerf$	Saw kerf (mm)	3
$FeedstockLength$	Length of the LVL feedstock boards (mm)	3100

3.5 Utilisation and processing rates, capital costs and non-labour operating costs

The utilisation rate of equipment, processing rates, upfront capital costs and non-labour operating costs adopted for the analysis are reported in Table 5. These values have been adopted from Venn *et al*. (2020), Venn and McGavin (2021) and Venn *et al*. (2021).

The green veneering processing rates reported in Table 5 were determined from equations reported in Venn *et al*. (2020). A lathe operating speed of 40 lm/min was assumed. Production of dry veneer is determined by the number of decks of the dryer, with more decks allowing a greater volume of dry veneer to be produced per hour. The analysis assumes the facility employs a three-deck dryer with an hourly throughput of 4.8 m^3 of green veneer per hour and a utilisation rate of 85% (Venn *et al*. 2021). The rates at which LVL can be produced is determined by: (1) the time required for the adhesive to cure (as described in the veneer and LVL product scenarios); (2) the charge capacities of the hot and cold presses, which have been set for analysis at 1.67 m^3 and 4.0 m^3, respectively; and (3) the press utilisation rate (Venn *et al*. 2021). The utilisation rates for hot presses in one-stage LVL manufacture and for cold presses in two-stage LVL manufacture were set to 50% and 80%, respectively (Venn *et al*. 2021).

A time and motion study was undertaken in August 2022 to observe the manufacturing process of finger-jointed sawn boards. Based upon information provided during the visit regarding the frequency of blade changes, cleaning and machine breakdowns, the utilisation rate of the finger-jointing machine was estimated to be 52.8% for spotted gum boards, 49.1% for ironbark and 42.9% for blackbutt. An average utilisation rate of 48.3% was used for this analysis.

Equations 3 to 6 determine the hourly processing rate of the finger-jointing machine. The variables, and their assigned values, used in these equations are defined in Table 6. Variables with no defined value in Table 6 represent derived variables whose values are determined from Equations 3 to 6. The total length of LVL feedstock that can be processed into finger-jointed LVL per hour is dependent on four main factors: (1) the length of the feedstock boards; (2) the number of boards that can be processed by the finger-jointing machine at a single time (this is limited by the width of the finger-joint conveyor and the width of the LVL boards being loaded (Equation 4)); (3) the length of the finger-jointed LVL being produced; and (4) the pressing time when the machine presses the finger-joints together. These four factors are what derive the linear metre per hour rates in Table 5.

It is expected that doubling the length of the feedstock boards or doubling the number of boards being loaded together can double the production of the finger-joint machine (Equation 3) until the rate of production reaches the maximum rate of production (Equation 5). The maximum rate of production of finger-jointing is limited by the pressing time (Equation 6). The observed pressing time during the time and motion study was 20 seconds per finger-jointed LVL board, which was also adopted in this analysis. At this rate, the press at the end of the finger-jointing production line is operating at 100% capacity. Although the linear metres of feedstock that can be processed is the same for finger-jointed one-stage or two-stage LVL (so long as the feedstock lengths are the same), the volume of hourly throughput is likely to be different because two-stage LVL feedstock has larger dimensions than the one-stage LVL (Table 3). Therefore, a greater volume of finger-jointed two-stage LVL can be produced per time period than finger-jointed one-stage LVL.

Table 5. Veneer, LVL and finger-joint utilisation, processing recovery rates, and upfront capital and operating costs

Parameter	Processing stage				
	Green veneer	Dry veneer	One-stage LVL	Two-stage LVL	Finger-jointing
Utilisation rate (%)	65 (Lathe)	85 (Dryer)	50 (Hot press)	80 (Cold press)	48 (Finger-joiner)
Hourly throughput volume at 100% utilisation (m^3/h)	20.15 m^3/h of salvage logs, 20.95 m^3/h of optional sawlogs, or 21.54 m^3/h of compulsory sawlogs per lathe (1 lathe in total)	4.8 m^3/h of green veneer per dryer (1 dryer in total)	5 m^3/h of dry veneer per hot press (2 hot presses in total)	0.5 m^3/h of one-stage LVL per cold press (4 cold presses in total)	1098 lm/h of LVL per finger-jointer (1 finger-jointer in total) [a]
Modelled hourly throughput volume (m^3/h) [b]	13.10 m^3/h of salvage logs, 13.62 m^3/h of optional sawlogs, or 14.00 m^3/h of compulsory sawlogs per lathe	4.08 m^3/h of green veneer per dryer	2.5 m^3/h of dry veneer per hot press	0.4 m^3/h of one-stage LVL per cold press	527 lm/h of LVL per finger-jointer [c]
Upfront capital cost in year zero ($ millions)	4.38	0.82	1.95	0.89	0.94
Maintenance and insurance costs (% of capital costs in year zero)	5 and 1.5	5 and 1.5	5 and 1.5	5 and 1.5	5 and 1.5
Non-labour operating costs ($/$m^3$ of log processed)					
Electricity	2.67	6.67		4.0[d]	
Water	0.69	-	-	-	-
Boiler feedstock	4.32	-	-	-	-
Consumables, compliance, and marketing	0.80	0.33	1.23	1.30	1.30
Other non-labour operating costs ($/$m^3$ of input product)					
PF glue		-	58.40	-	-
RF glue		-		4.72	6.81
Packaging ($/$m^3$ of final product)		-	0.24	0.24	0.24

Note: a. Linear rates of throughput are multiplied by the width and thickness of the LVL feedstock to determine hourly throughput volumes of LVL

b. Modelled hourly volume of throughput at each stage of production is equal to the hourly volume of throughput of feedstock at 100% utilisation * utilisation rate

c. The 1098 lm h^{-1} of LVL throughput per finger-jointer is multiplied by the width and thickness of the LVL throughput product to calculate the hourly throughput volume of finger-jointed LVL.

d. Industry experts were unable to segregate energy consumption for one-stage LVL, two-stage LVL and finger jointing manufacture. An electricity cost of $4 m^{-3} of log has been applied once regardless of the final product type.

$$LMPH = \frac{Boards * FeedstockLength}{ObservedProcessTime} \quad \text{[Eq. 3]}$$

$$Boards = \frac{FeedstockWidth}{ConveyorWidth} \quad \text{[Eq. 4]}$$

where:

$$LMPH \leq MaxRate * 3600 \quad \text{[Eq. 5]}$$

$$MaxRate = \frac{PreDockLength}{PressingTime} \quad \text{[Eq. 6]}$$

Table 6. Variables in Equations 3 to 6 and the values adopted in the analysis

Variable name	Description	Value used in analysis
$LMPH$	Linear metres of LVL processed per hour by the finger-jointing machine (lm/h)	-
$Boards$	Number of LVL feedstock boards loaded into the finger-jointing machine at a given time	-
$FeedstockLength$	Length of the LVL feedstock boards (mm)	3100
$ObservedProcessTime$	Observed time taken to process one metre of LVL feedstock at the Robertson Brothers (s)	20.4
$FeedstockWidth$	Width of LVL feedstock (mm)	**
$ConveyorWidth$	Width of finger-jointing conveyor	750
$MaxRate$	Maximum linear metre throughput of the finger-jointing machine (lm/s)	0.305
$PreDockLength$	Length of the finger-jointed LVL prior to docking (mm)	6100
$PressingTime$	Pressing time of the finger-jointing machine (s)	20

Note: **$FeedstockWidth$ varies with each LVL product. These widths are listed in Table 3.

3.6 Product manufacturing costs

Tables 5 and 7 report the EWP manufacturing costs. Further details about the capital costs and asset lives of individual building and equipment items are provided in the Appendix. For this case study, the same capital equipment is utilised for both the 10,000 m^3/y and 15,000 m^3/y log processing scales. Capital costs are cumulative with value-adding. For example, the total capital costs of manufacturing one-stage LVL is the sum of the capital costs of green veneer, dry veneer, and one-stage LVL. When the asset life is reached for any particular piece of equipment, the asset has a residual value of 5% of its cost and requires replacement at its listed capital cost. Venn *et al*. (2021) provided additional information about the cost, life and quantity required of specific assets. To depreciate assets, the prime cost method was used on assets with a productive life less than or equal to 15 years, whilst a diminishing value depreciation rate of 2.5% and 15% was applied to buildings and equipment, respectively, when useful life was greater than 15 years.

All buildings and equipment constructed or installed at the beginning of the investment period are assumed to have been purchased with 30% cash and the remainder borrowed at 6% per annum over ten years. All equipment purchased in later years to replace items that have reached the end of their useful life are paid from operating cash in the year of acquisition (Venn *et al*. 2021). Annual maintenance and insurance costs are estimated as a proportion of capital costs in year zero, as specified in Table 5. Operating costs that do not vary by marketable product have been expressed in dollars per cubic metre of log processed in Table 5. Operating costs that do vary by marketable product have been expressed in dollars per cubic metre of final product. Gross profits have been taxed at 25%.

Insufficient data were available from research partners to apportion electricity costs between one-stage LVL, two-stage LVL and finger-joint manufacture. In the analysis, regardless of whether one-stage LVL, two-stage LVL or finger-jointed LVL is produced, the electricity cost of \$4 m^{-3} of log is applied once. The additional energy cost of converting one-stage LVL into two-stage LVL is marginal, because the additional processing is limited to gluing one-stage LVL in a cold press for 8 h. This electricity cost is cumulative with the drying and veneering electricity costs.

Table 7 reports the salaries, hourly labour costs and the number of full-time equivalent (FTE) workers required per shift at each stage of production, as estimated by Venn *et al*. (2021). A shift is eight hours per day, five days per week, 48 weeks per year, for a total of 1920 hours per year. Processing rates at each stage of production (Table 5) are used by the financial model to estimate the annual number of hours of labour required for each processing stage by log procurement scenario. Labour costs in Table 7 are cumulative, such that total labour costs for one-stage LVL manufacture are the summation of labour costs of administration, green veneer production, dry veneer production and one-stage LVL manufacture. The hourly labour costs reported in Table 7 are inclusive of an on-cost of 36.9% which is comprised of 12% superannuation, 4.5% payroll tax, 0.4% worker’s insurance, 10% worker’s compensation and a 10% contingency cost to accommodate for the hire of temporary workers for when hired mill employees are away.

Table 7. Labour costs by stage of production for a processing scale of 15,000 m^3 of log per annum

Position	Annual salary ($)	Hourly cost ($ FTE h^{-1})	Number of FTEs by processing stage					
			Admin	Green veneer	Dry veneer	One-stage LVL	Two-stage LVL	Finger-jointing
Manager	150,000	114	1	0	0	0	0	0
Senior administration	80,000	61	1	0	0	0	0	0
Supervisor/Maintenance	80,000	61	0	0.25	0.25	1.25	0	0
Loader/ machine operators	55,000	42	0	3	0	8	1	1
Machine assistants	45,000	34	0	2	3	0	0	2
Administration support	45,000	34	1	0	0	0	0	0
Quality control supervisor	80,000	61	1	0	0	0	0	0
Packaging	45,000	34	0	0	0	0	0	0
Total number of FTEs			*4*	*5.25*	*3.25*	*9.25*	*1*	*3*

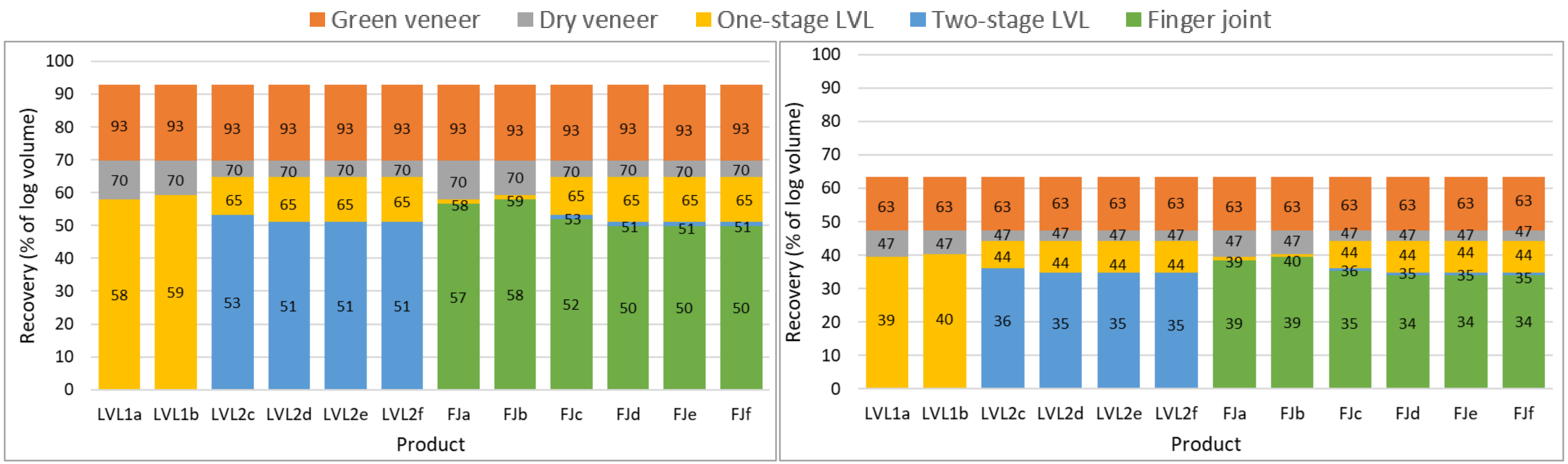
4. Results

The scenarios analysed were designed to test and demonstrate progress on the development of the mathematical programming model, in particular the addition of a finger-jointing manufacturing process in the model. These results are intended to inform the Robertson Brothers about the financial performance of manufacturing LVL products under various log procurement and log processing scale scenarios. Sensitivity tables have been reported in the Appendix and display the profits per cubic metre of final product by log processing scale and log procurement scenario. For the sensitivity analyses, base case parameter levels for the mill-delivered log costs were increased and decreased by 10% and 30%.

4.1 Recovery of intermediate and final products under various log procurement scenarios

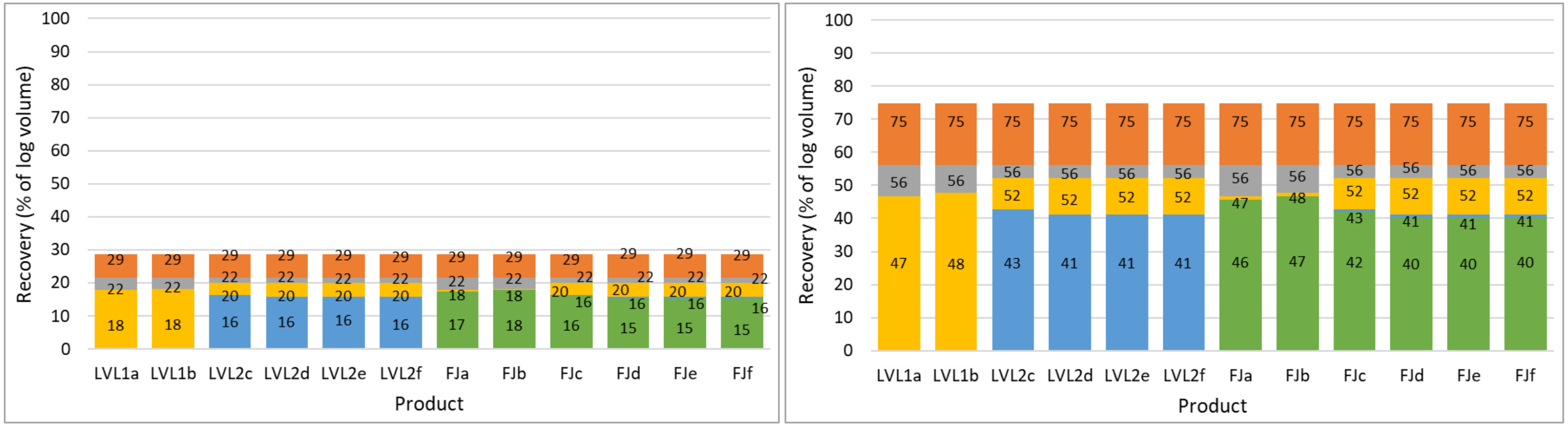
Figure 3 illustrates the recovery of intermediate and final products as a proportion of log volume by log type. Due to their large diameter and relatively low levels of sweep, compulsory sawlogs have the highest recovery rates of the three log types. In contrast, salvage logs, due to their small diameter and high levels of sweep, only generate a green veneer recovery of 29%. Since compulsory sawlogs make up approximately 62% of the Robertson Brothers’ current log intake, utilising their current log type composition results in a comparatively high rate of recovery. The differences in recovery rates between final products at the same stage of production (such as between LVL1a and LVL1b, or LVL2c and LVL2d) are due to differences in final product dimensions, with a higher volume of LVL1b beams able to be recovered from a one-stage LVL panel than LVL1a beams (this is further explained in Section 3.4).

In Figure 3, two-stage LVL and finger-jointed two-stage LVL final products report a higher intermediate one-stage LVL recovery than the final recovery of one-stage LVL products. This is because one-stage LVL final products (such as LVL1a or FJa) report the recovery of LVL beams that have been sawn from one-stage LVL panels, whilst two-stage LVL final products (such as LVL2c or FJc) report the recovery of the unsawn one-stage LVL panels. To produce two-stage LVL final products, the one-stage LVL panels are not sawn up into one-stage LVL beams, so there is no recovery loss due to merchandising. Rather, they are glued together to produce two-stage LVL panels which are then sawn into two-stage LVL beams. Finger-jointed one-stage LVL products have a higher final recovery than finger-jointed two-stage LVL products since the one-stage LVL beams, which provide feedstock for finger-jointed one-stage LVL, have a higher recovery from one-stage LVL panels than two-stage LVL beams from two-stage LVL panels. This is because the greater widths of the two-stage LVL beams results in more wasted panel volume (see Figure 2).



(a) Compulsory sawlogs

(b) Optional sawlogs



(c) Salvage logs

(d) Current log type mix

Figure 3. Recovery rates of final products from log type by processing stage, log type and log processing scale

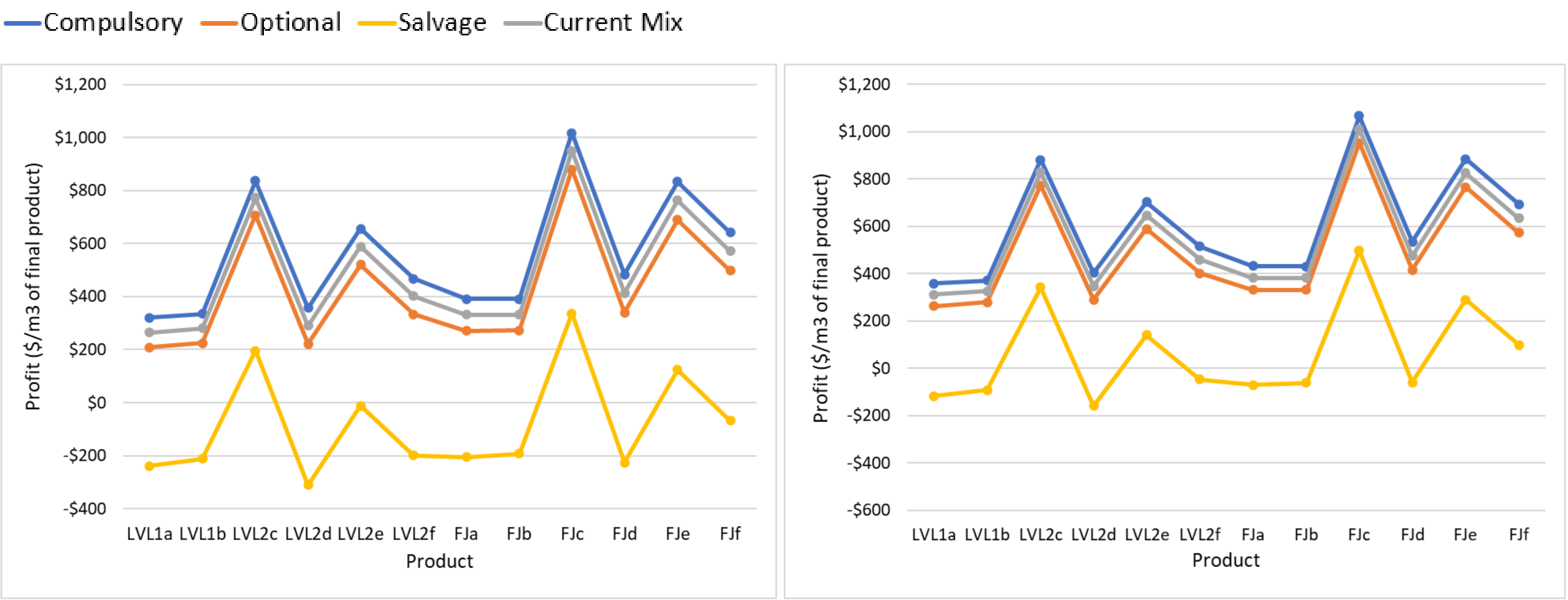
4.2 Financial performance of final products

Figures 4 to 7 illustrate the financial performance of manufacturing the twelve final products under the 10,000 m^3/y and 15,000 m^3/y log processing scales. Figure 4 displays the profit per cubic metre of final product by log processing scale and log type. Utilising only compulsory or optional logs, or using the current blend of log types, is expected to generate a positive return for all products under both log processing scales, with compulsory logs generating the highest profits out of the four log procurement scenarios for all final product scenarios despite their high MDLC (Table 2). Due to their low levels of recovery (Figure 3), utilising only salvage logs generates a positive return to only LVL2c, FJc and FJe under the 10,000 m^3/y scale and LVL2c, LVL2e, FJc, FJe, FJf under the 15,000 m^3/y scale.

Figures 5 and 6 display the average costs and profits per cubic metre by final product and log processing scale under the current Robertson Brothers' log intake. Figure 5 identifies the costs at each stage of production and Figure 6 separates the costs by cost component throughout the entire production process. Market price was the largest contributor to a product's financial performance with the five highest priced products (FJc, FJe, LVL2c, FJf and LVL2e (shown in Table 3)) also being the five most profitable (FJc, LVL2c, FJe, LVL2e, and FJf). There were instances where products with a lower price generated a higher profit per cubic metre than products with a higher price (such as LVL2c vs FJe and LVL2e vs FJf). This is because of the higher manufacturing costs (e.g. capital and labour) and lower recovery of marketable product from log volume that arise with increased value-adding.

The costs at the finger-jointing stage are highly dependent on whether one-stage or two-stage LVL feedstock is used. Because the finger-jointer can process the same linear metreage of throughput per hour for both one-stage or two-stage LVL and since two-stage LVL feedstock beams have a larger volume than one-stage LVL feedstock, more finger-jointed volume can be produced when processing two-stage LVL. This reduces the number of hours required to process the feedstock and thus, the labour costs are smaller for finger-jointed two-stage LVL at the finger-jointing stage. This is why manufacturing costs at the finger-joint stage in Figure 5 are smaller for finger-jointed two-stage LVL (FJc to FJf) than for finger-jointed one-stage LVL (FJa and FJb).

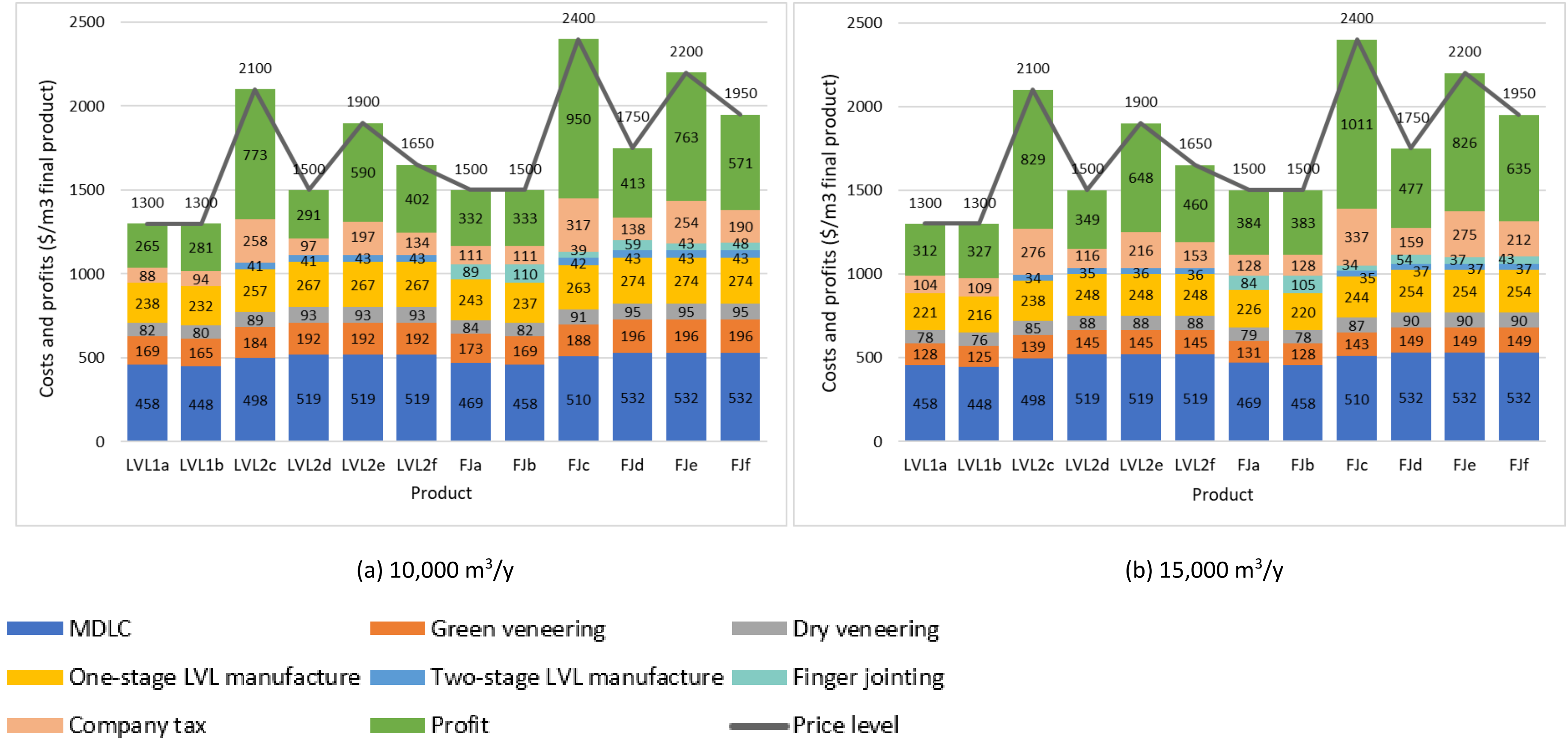
The impact of log processing scale on the profit per cubic metre of final product is also evident in Figures 5 and 6. In all final product and log procurement scenarios, increasing the log processing scale from 10,000 m^3/y to 15,000 m^3/y improved the profitability. The only cost types affected by changes in log processing scale are the capital costs and tax. Since the same equipment is utilised for both log processing scales, higher final product volumes cause the average capital cost per cubic metre of final product to decline, which increases the before-tax profit per cubic metre of each final product. The increase in before-tax profit leads to a proportional increase in tax payable. Since the increase in tax is less than the reduction in capital costs as a result of the increase in log processing scale, the profit per cubic metre of final product is higher at the larger processing scale.



(a) 10,000 m^3/y

(b) 15,000 m^3/y

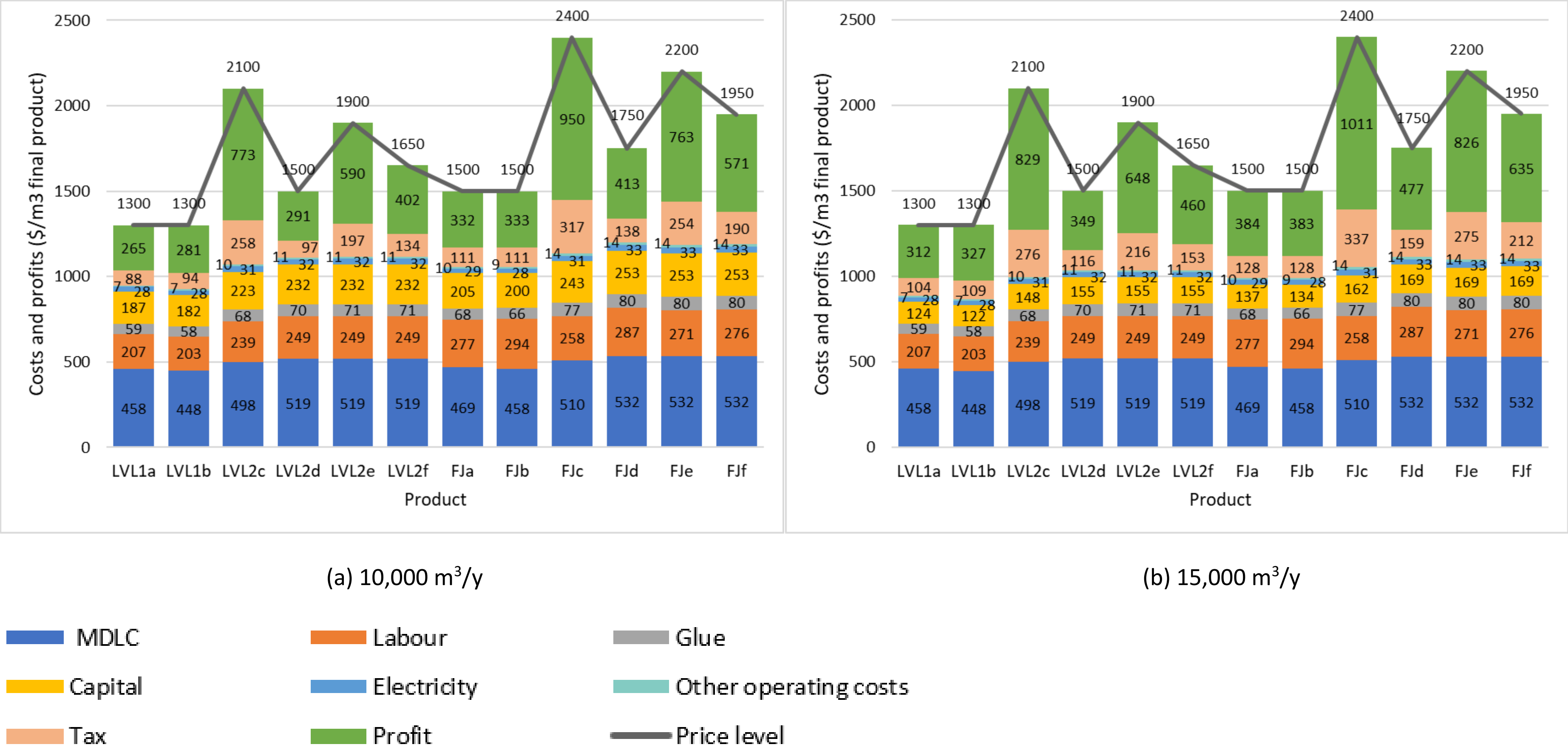
Figure 4. Profit ($/m^3) of final product by log type and log processing scale



(a) 10,000 m^3/y

(b) 15,000 m^3/y

Figure 5. Costs, prices and profits ($/m^3) of final product by processing stage and log processing scale under the current log mix at the Robertson Brothers



(a) 10,000 m^3/y

(b) 15,000 m^3/y

Figure 6. Costs, prices and profits ($/m^3) of final product by cost element and log processing scale under the current log mix at the Robertson Brothers

Net present values (NPVs) are presented in Figure 7, with all final product and log processing scale scenarios under the current blend of log types being financially viable, with NPVs and ranging from $11.3 to $84.1 million. The NPVs highlight the impact of log processing scale on the financial performance of LVL manufacture, with the 15,000 m^3/y scale generating far superior returns than the 10,000 m^3/y scale. The analysis also illustrated that although some two-stage LVL products generated lower returns than one-stage LVL (e.g., LVL2d vs LVL1b) and some finger-jointed products generated lower profit than two-stage LVL products (FJd vs LVL2c), upgrading one-stage and two-stage LVL products to finger-jointed products (such as upgrading LVL1a to FJa, or LVL2f to FJf) was found to improve the financial performance of LVL manufacture, with the higher product prices justifying the additional infrastructure investment and labour and operating costs.

5. Conclusions

The analyses carried out in this report highlight the impacts of log selection and log processing scale on the financial performance of LVL and finger-jointed products. The results highlight the financial benefits of using large, straight sawlogs for the manufacture of veneer-based EWPs. Given assumptions made in this report about the geometry of different log types, high recovery of green veneer from compulsory sawlogs generated the highest profit levels out of the four log procurement scenarios despite their high MDLCs. This is also the first milestone report to report the financial performance of finger-jointing and has demonstrated the potentially lucrative returns associated with their manufacture.

The next milestone report will focus on parameterising the mill to market module within the mathematical model for Fiji. The resulting model will be able optimise log selection, log processing scale, facility location, final product, and scale of capital equipment. This work is expected to be completed in February 2024.

6. References

McGavin, R. L., Bailleres, H., Lane, F., Blackburn, D., Vega, M., & Ozarska, B. (2014a). Veneer recovery analysis of plantation eucalypt species using spindleless lathe technology. *BioResources*, *9*(1), 613-627.

McGavin, R. L., Bailleres, H., Lane, F., Fehrmann, J., & Ozarska, B. (2014b). Veneer grade analysis of early to mid-rotation plantation eucalyptus species in Australia. *BioResources*, *9*(4), 6562-6581.

McGavin, R. L., & Leggate, W. (2019). Comparison of Processing Methods for Small-diameter Logs: Sawing *versus* Rotary Peeling. *BioResources*, *14*(1), 1545-1563.

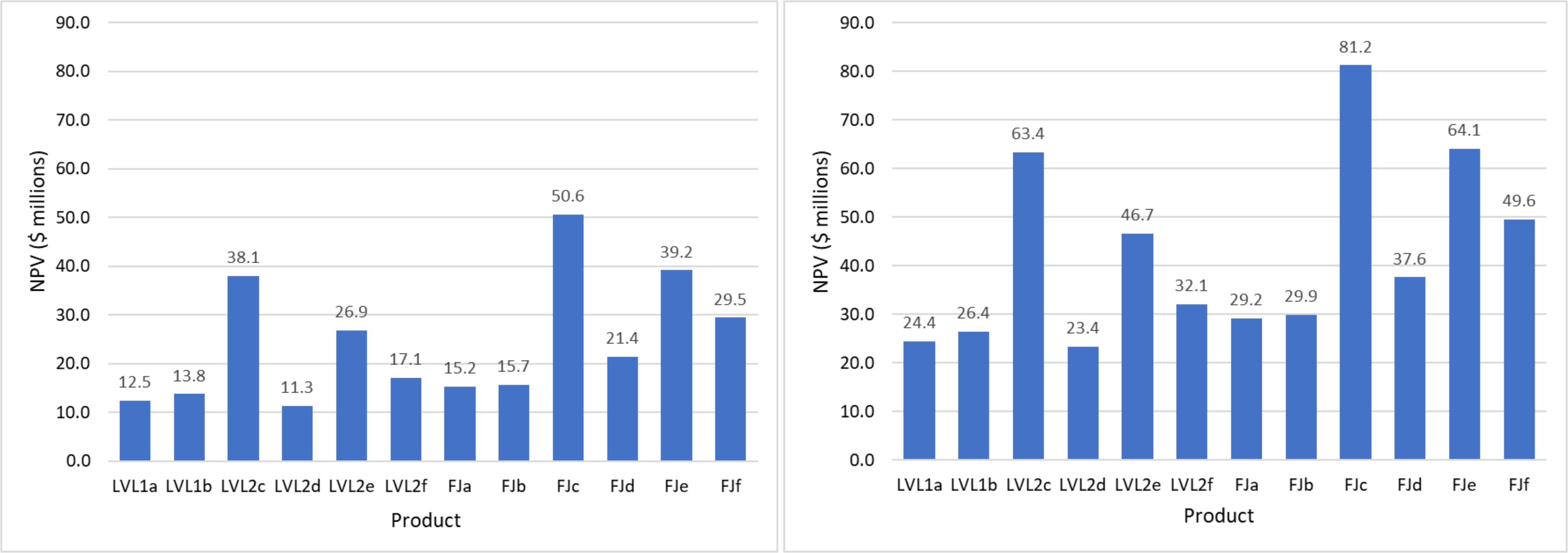
Queensland Department of Primary Industries - Forestry, 2001. Hardwood sawlog classification guidelines, 3rd edition. DPI-Forestry, Brisbane.

Venn, T. J., Dorries, J. W., & McGavin, R. L. (2021). A mathematical model to support investment in veneer and LVL manufacturing in subtropical eastern Australia. *Forest Policy and Economics*, *128*, DOI: https://doi.org/10.1016/j.forpol.2021.102476.

Venn, T. J., Dorries, J. W., & McGavin, R. L. (2022). Progress on the "Mill-gate to manufactured EWP" module from the Mathematical Programming Model to Support Engineered Wood Product Manufacturing Decisions. Milestone report 3 for ACIAR project number FST/2019/128, Coconut and Other Non-traditional Forest Resources for the Manufacture of Engineered Wood Products, The University of Queensland.

Venn, T. J., & McGavin, R. L. (2021). A decision-support system to assist forest industry planning and investment when data are scarce: the case of hardwood veneering in subtropical eastern Australia. *Australian Forestry*, *84*(2), 59-72.

Venn, T. J., McGavin, R. L., & Ergashev, A. (2020). Accommodating log dimensions and geometry in log procurement decisions for spindleless rotary veneer production. *BioResources*, *15*(2), 2385-2411.



(a) 10,000 m^3/y

(b) 15,000 m^3/y

Figure 7. Net present value (NPV) by final product and log processing scale under the current log mix at the Robertson Brothers

7. Appendix

Table A1. Capital costs for green veneer production

Item	Unit cost with installation ($)	Asset life (years)	Number of units employed
Water storage	82,500	20	1
Log steaming/ bathing chamber	75,000	15	1
Biomass boiler	3,105,000	20	1
Log docking saw	23,000	10	1
Log charger	7100	15	1
Log conveyer	15,900	15	1
Log debarker/ rounder	52,000	5	1
Waste chipper	230,000	15	1
Waste wood conveyer	20,700	15	2
8-foot spindleless lathe	130,740	5	1
Veneer conveyor	20,700	15	1
Veneer stacker	67,740	10	1
Veneer clipper	58,030	10	1
Knife grinder	33,000	20	1
Control room	90,000	30	1
Veneer trolleys	10,000	5	2
Wrapping machine	17,250	5	1
Industrial bin	5000	10	1
Forklift (second hand)	30,000	4	1
Buildings (360 m^2)	270,000	30	1
Fuel bin for boiler	5000	10	1
Total up-front capital costs for green veneer production			*$4,379,350*

Table A2. Capital costs for dry veneer production

Item	Unit cost with installation ($)	Asset life (years)	Number of units employed
Jet dryer (small)	417,190	20	1
Automatic feeder	69,000	7	1
Dry veneer conveyer	20,700	5	1
Trolleys	10,000	5	1
Forklift	30,000	4	1
Buildings (360 m^2)	270,000	30	1
Total up-front capital costs for dry veneer production			*$816,890*

Table A3. Capital costs for one-stage LVL manufacture

Item	Unit cost with installation ($)	Asset life (years)	Number of units employed
Glue spreader	41,050	5	1
Glue mixer	15,200	5	1
Glue/resin storage	133,000	25	1
Trim saw	25,840	5	1
Sanding machine	139,860	6	1
Cold press	110,000	15	1
Hot press	117,700	20	2
LVL conveyers	19,800	5	1
LVL assembly	30,400	7	1
LVL stacker	67,740	5	2
Hydraulic lifter	4100	5	1
Dust extraction and briquette machine	187,000	20	1
Waste conveyer	19,800	5	1
Waste chipper	220,000	30	1
LVL storage	44,000	8	1
Buildings (360m^2)	270,000	30	1
LVL testing machine	19,760	10	1
Lab equipment for oven, viscometer, hot plates, specific gravity etc.	4400	10	1
Product development	22,000	10	1
Total up-front capital costs for one-stage LVL production			*1,947,100*

Table A4. Capital costs for two-stage LVL manufacture

Item	Unit cost with installation ($)	Asset life (years)	Number of units employed
Glue spreader	41,050	5	1
Glue mixer	15,200	5	1
Glue/resin storage (15,000L)	133,000	25	1
Trim saw	25,840	5	1
Cold press	110,000	15	4
Plywood conveyers	19,800	5	1
LVL assembly	30,400	7	1
Beam saw	165,000	10	1
Product development	22,000	10	1
Total up-front capital costs for two-stage LVL production			*$892,290*

Table A5. Capital costs for finger-jointed LVL manufacture

Item	Unit cost with installation ($)	Asset life (years)	Number of units employed
Product development	22,000	10	1
Buildings	270,000	30	1
Finger joiner	558,250	15	1
Material Handling	50,750	10	1
auto stacker	40,600	10	1
Total up-front capital costs for finger-jointed LVL production			*$941,600*

Table A6. Sensitivity of average profit ($/m3 final product) of LVL and finger-joint manufacture to changes in the mill-delivered log costs

Final product	Log type	Log scale (m^3/y)	Profit ($/$m^3$ final product) by change in base case mill-delivered log cost (%)				
			-30	-10	0	+10	+30
LVL1a	Compulsory	10,000	418	353	321	289	224
		15,000	456	391	359	327	262
	Optional	10,000	317	244	208	172	100
		15,000	372	300	264	228	156
	Salvage	10,000	-82	-187	-239	-292	-397
		15,000	41	-63	-116	-168	-273
	Current mix	10,000	368	300	265	231	162
		15,000	415	346	312	278	209
LVL1b	Compulsory	10,000	430	367	336	304	241
		15,000	468	404	373	341	278
	Optional	10,000	331	261	225	190	119
		15,000	386	315	280	244	174
	Salvage	10,000	-58	-161	-212	-263	-366
		15,000	62	-40	-92	-143	-246
	Current mix	10,000	382	315	281	248	181
		15,000	428	360	327	293	226
LVL2c	Compulsory	10,000	942	872	837	801	731
		15,000	988	917	882	847	776
	Optional	10,000	825	747	707	668	589
		15,000	892	813	774	735	656
	Salvage	10,000	367	253	196	139	24
		15,000	514	400	343	286	172
	Current mix	10,000	885	810	773	736	661
		15,000	941	866	829	791	717
LVL2d	Compulsory	10,000	467	394	357	320	247
		15,000	514	441	404	367	294
	Optional	10,000	345	263	222	181	99
		15,000	415	333	292	251	169
	Salvage	10,000	-132	-251	-311	-370	-489
		15,000	21	-98	-157	-217	-336
	Current mix	10,000	408	330	291	252	174
		15,000	466	388	349	310	232
LVL2e	Compulsory	10,000	766	693	656	619	546
		15,000	813	740	703	666	593
	Optional	10,000	644	562	521	480	398
		15,000	714	632	591	550	468
	Salvage	10,000	167	48	-12	-71	-190
		15,000	320	201	142	82	-37
	Current mix	10,000	706	629	590	551	473
		15,000	764	687	648	609	531

Final product	Log type	Log scale (m^3/y)	Profit (\$/m^3 final product) by change in mill-delivered log cost (%)				
			-30	-10	0	+10	+30
LVL2f	Compulsory	10,000	579	505	468	432	358
		15,000	626	552	516	479	405
	Optional	10,000	457	375	334	293	211
		15,000	526	444	403	362	280
	Salvage	10,000	-21	-140	-199	-259	-378
		15,000	133	14	-46	-105	-224
	Current mix	10,000	519	441	402	363	285
		15,000	577	499	460	421	343
FJa	Compulsory	10,000	491	425	391	358	292
		15,000	533	466	433	400	334
	Optional	10,000	382	308	271	234	160
		15,000	443	369	332	295	221
	Salvage	10,000	-44	-151	-205	-259	-366
		15,000	92	-16	-70	-123	-231
	Current mix	10,000	438	367	332	297	227
		15,000	489	419	384	348	278
FJb	Compulsory	10,000	488	423	390	358	293
		15,000	528	464	431	399	334
	Optional	10,000	381	309	273	237	164
		15,000	441	369	333	297	224
	Salvage	10,000	-35	-140	-193	-245	-350
		15,000	97	-8	-60	-113	-218
	Current mix	10,000	436	367	333	298	229
		15,000	486	417	383	348	280
FJc	Compulsory	10,000	1126	1054	1018	982	910
		15,000	1176	1104	1067	1031	959
	Optional	10,000	1001	921	880	840	759
		15,000	1074	993	953	913	832
	Salvage	10,000	512	395	337	278	161
		15,000	673	556	497	439	322
	Current mix	10,000	1065	989	950	912	835
		15,000	1126	1049	1011	973	896
FJd	Compulsory	10,000	596	521	484	446	371
		15,000	648	573	535	498	423
	Optional	10,000	466	382	340	298	214
		15,000	542	458	416	374	290
	Salvage	10,000	-43	-165	-226	-287	-408
		15,000	124	3	-58	-119	-241
	Current mix	10,000	533	453	413	373	294
		15,000	596	516	477	437	357

Final product	Log type	Log scale (m^3/y)	Profit ($\$/\mathrm{m}^3$ final product) by change in mill-delivered log cost (%)				
			-30	-10	0	+10	+30
FJe	Compulsory	10,000	946	871	833	796	721
		15,000	998	923	885	847	772
	Optional	10,000	816	732	690	648	564
		15,000	892	808	766	724	640
	Salvage	10,000	307	185	124	63	-59
		15,000	474	352	291	230	109
	Current mix	10,000	883	803	763	723	643
		15,000	946	866	826	786	707
FJf	Compulsory	10,000	755	679	642	604	529
		15,000	806	731	693	656	581
	Optional	10,000	624	540	498	457	373
		15,000	700	616	574	532	448
	Salvage	10,000	115	-7	-67	-128	-250
		15,000	283	161	100	39	-83
	Current mix	10,000	691	611	571	532	452
		15,000	754	675	635	595	515