Hedonic prices for structural wood attributes of radiata pine logs in New Zealand

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Abstract

This paper presents an estimation of the economic values of attributes for the production of structural timber from *Pinus radiata* logs. A hedonic prices approach was used to obtain economic values, using conversion return instead of log price as the dependent variable. A comparison between these log values is presented to illustrate the pertinence of the conversion return for the purposes of this study. Data were provided by the Wood Quality Initiative as a sample of 71 second and third unpruned logs. Attributes included in the hedonic models were small end diameter, stiffness, basic density, and branches and the corresponding hedonic prices were 0.11, 0.029, 0.37 and -0.55 NZ $\$/m^3$ respectively. Additionally, an efficiency analysis was used to identify the mix of wood attributes that define an efficient log for structural purposes, from a technical and economic point of view. The application of data envelopment analysis showed that a third log is the most efficient to produce structural grade MSG8+. This log also presented the highest difference between conversion return and its corresponding price. Trends observed in the cost efficiency index, as well as correlations between this and the log conversion return were useful for validating the economic values of the wood attributes.

Keywords: economic values, log attributes, structural lumber, hedonic models, DEA.

Introduction

Structural timber has specific physical and mechanic requirements that are determined by key wood attributes such as stiffness, strength and density. In New Zealand, wood stiffness has become imperative since the introduction of the NZ standard NZS3622:2004 of verification of timber properties. Under this norm, structural timber must have its bending strength and stiffness verified. Growers that produce logs for structural purposes are focussing on silvicultural regimes and genetic material that improve traits such as stiffness following the market's demands (Roth et al. 2007). Consequently, in recent years the New Zealand breeding program has been more committed to these wood properties (Sorensson et al. 1997; Kumar et al. 2002).

There have also been significant advances in rapid and non-destructive techniques to identify and measure characteristics for solid wood. Currently there is access to SilviScan to assess physical attributes, near infrared spectroscopy (NIR) to obtain chemical and physical properties, and acoustics tools to estimate stiffness. As an example, the use of acoustic segregation criteria has provided economic advantages to processing plants, as well as contributed to the precision of the concept of wood quality, by providing information of wood traits at the timber, log, tree and even seedling level (e.g., Carter et al. 2006; Grabianowski et al. 2006; Lasserre et al. 2007). However, these advances have not been reflected in economic values for wood attributes, which are required by tree breeders.

Bioeconomic models are the most common methodology to obtain economic values, by observing the difference in profitability due to unit changes in a trait for a given production system (Borralho et al. 1993; Ivković et al. 2006). Alternative approaches have been linear programming (e.g., Ladd and Gibson 1978), the application of efficiency measures of inputs on production systems (Todoroki and Carson 2003) and hedonic models.

The economic literature presents hedonic models as the most suitable way to value the attributes of a good. Hedonic values are the implicit prices of characteristics and they are revealed to economic agents from observed prices of differentiated products and the specific quantities of characteristics associated with them (Lancaster 1966; Rosen 1974; Lucas 1975). This approach has been widely used in the housing market (Palmquist 1984; Rothenberg et al. 1991) and to estimate attribute values of agricultural commodities (Ladd and Gibson 1978; Espinosa and Goodwin 1991; Bowman and Ethridge 1992). Hedonic methods have also been applied to obtain wood attributes (e.g., Aubry et al. 1998; Alzamora and Apiolaza 2009). There are also studies that report log value regressions on wood attributes but they are not proper hedonic models. However, they present interesting information about which log characteristics explain the lumber grade recovery and the value recovery of logs (e.g., Cotterill and Jakcson 1985; Beauregard et al. 2002).

This study presents an application of hedonic prices to estimate the value of wood attributes for the production of structural timber from radiata pine in New Zealand. The log traits considered in this work are: small end diameter (SED), branch index (BI), basic wood density (BDENS), and wood stiffness (STF). Final products correspond to structural grades: MSG6, MSG8, MSG10 and MSG12. The recovery value of logs is used as response variable in the hedonic models; nevertheless, we also present a comparative analysis between log prices and recovery values. Additionally, an efficiency analysis was used to identify the mix of wood attributes that define an efficient log for structural purposes, from a technical and economic point of view.

Materials and methods

The data for this project came from a structural sawing study conducted by the New Zealand Wood Quality Initiative (WQI). The sawing study considered 36 stems (18 from each of two forests) to produce 5m long second and third logs to yield 71 structural logs. Table 1 presents a summary of the information at the log level. Acoustic measurements of logs used a Director HM200 tool.

Table 1: Average value of log descriptors segregated by log class.

Variable		Second log	Third log
Number of logs	No	35	36
Log length (LL)	m	5	5
Small end diameter (SED)	mm	449.057	397.722
Log volume (VOL)	m^3	0.895	0.729
Log commercial volume (COVOL)	m^3	0.448	0.365
Taper (TP)	mm/m	8.246	10.056
Branch index (BI)	mm	49.600	59.389
Largest branch (LB)	mm	60.286	73.333
Stiffness (STF)	MPa	7938.73	7928.638
Basic density (BD)	kg/m^3	382.343	377.972
Green density (GD)	kg/m^3	906.971	919.611

The processing strategy was to cant saw, maximising the recovery of 100x50 mm structural lumber. Broken full length boards were kept but short boards and 25mm boards were excluded from the study. The resulting lumber (1300 boards) was machine stress graded twice. The stress grader captured all the grading information at 152mm increments along the

lumber with the first and last 700mm of the lumber being ungraded. Timber MSG12 was generated in 21% of the logs and the grade MSG8+ was produced in 83% of the logs.
The sawing study did not consider the information from some defective boards (e.g broken), which we had to recover to estimate the log recovery value. This was accomplished by estimating the commercial volume of logs using the average sawing yield of logs with complete information. Then, we obtained the commercial volume by product applying the average participation for each timber grade. Finally, the commercial volume by product was divided by the volume of one lineal meter of board to find the number of boards.

Hedonic models. Hedonic price functions can be presented as regressions of the form:

$$p_i = f(a_{i1}, a_{i2}, \ldots, a_{in}; e_i)$$

where p_i is the observed price of log *i*, a_{in} measures the amount of some wood quality per unit of log, and e_i is a random disturbance term. A suitable functional form for this model is then found by statistical performance. Models often mentioned in the literature are: linear, logarithmic, reciprocal, quadratic and Box-Cox transformations (e.g., Cropper et al. 1988).

This study uses conversion return (CR) instead of log price as indicator of log value. The conversion return represents the theoretical maximum willingness to pay for logs in $/m^3 delivered to the sawmill (Davis et al. 2004):

$$CR = TTV - PC$$

where *TTV* is timber value of one cubic meter of logs and *PC* is the corresponding processing cost. Table 2 presents prices and processing costs for structural timber obtained from New Zealand firms. The price of MSG12 was estimated by assuming that the price differential between MSG8 and MSG10 would be the same as between MSG10 and MSG12. Rejected products were valued at 50% of the MSG6 grade price.

Table 2: Prices and processing costs for structural timber (100x50 mm).

MSG6 [NZ $/linear m]	MSG8 [NZ $/linear m]	MSG10 [NZ $/linear m]	MSG12 [NZ $/linear m]	Reject products [NZ $/linear m]	Processing costs [NZ $/m^3]
2.5	3.2	4.1	4.8	1.3	180

Data envelopment analysis (DEA). It is a methodology to estimate non-parametric frontiers of efficiency on production. DEA involves the use of linear programming to construct a non parametric price-wise surface over the data. Thus, efficiency measures can be calculated relative to this surface (frontier). In DEA, efficiency is defined as the ratio of a linear combination of outputs over a linear combination of inputs. Observations that are not dominated by this frontier are considered 100% efficient. Domination occurs when another firm, or a linear combination of other firms, produces more of all outputs with the same input aggregate, using the same weights to aggregate inputs. A linear programming problem is solved separately for each observation (Van Biesebroeck 2007). In the case of the input oriented DEA, the problem is formulated as:

$$\min_{\theta,\lambda} \theta = \frac{X}{Q} \quad \textit{Subject to:} \quad \begin{aligned} -q_i + Q\lambda &\geq 0 \\ \theta x_i - X\lambda &\geq 0 \\ \lambda &\geq 0 \end{aligned}$$

where x_i is a *Kx1* vector of inputs of *i-th* firm, q_i is *Mx1* vector of outputs of *i-th* firm, *X* is *KxI* input matrix, *Q* is *MxI* output matrix, λ is an *Ix1* vector of constants and *θ* is a scalar

corresponding to the technical efficiency . The efficiency measure θ is interpreted as the productivity difference between the *i-th* firm and the most productive firm of the sample.
The advantages of this method are that i) it is not necessary to assume a particular production function and ii) it is also possible to assess multi-product and multi-input systems.
Commonly, DEA efficiency analysis is applied to firms; however in this study the unit of production is the log. Thus, inputs would be the log wood attributes and the products are structural timber grades MSG8+. In addition, the hedonic prices of logs' attributes are used as inputs costs in the cost efficiency DEA analysis. The efficiency analyses were carried out with the software FRONTIER Version 4.1 .

Results and discussion

Log prices versus conversion return: In New Zealand log prices of unpruned logs are basically defined in terms of SED and largest branch (LB). For instance, the highest price (S1) is fetched by logs with SED equal or greater than 400mm and maximum knot equal or lower than 60mm. Table 3 presents log prices and conversion returns (CR). As expected, the average CR was higher than the log price for all logs, with higher differences for logs S1 and S2. In addition, S1 and S2 logs obtained practically the same recovery values. The main distinction between these logs is SED –S1 logs are bigger– but their aptitude to produce structural grades is similar. Furthermore, the minimum CR of S1 logs was significantly lower than for S2 logs; that is, there were S1 logs with a negative economic return, even when satisfying the SED and LB requirements. In contrast, lower quality logs (e.g. L2 and L3) did not have a negative CR.

Figure 1 presents the relationship between log prices and wood traits that are not included in the segregation criteria (stiffness and wood density). There is a wide range of stiffness for any given log price, with a substantial overlap of stiffness across prices. This is particularly evident for S1 (86 NZ \$/m^3) and S2 (82 NZ \$/m^3) logs. An even more dramatic trend is observed for basic density, where there is almost complete overlap across price classes.

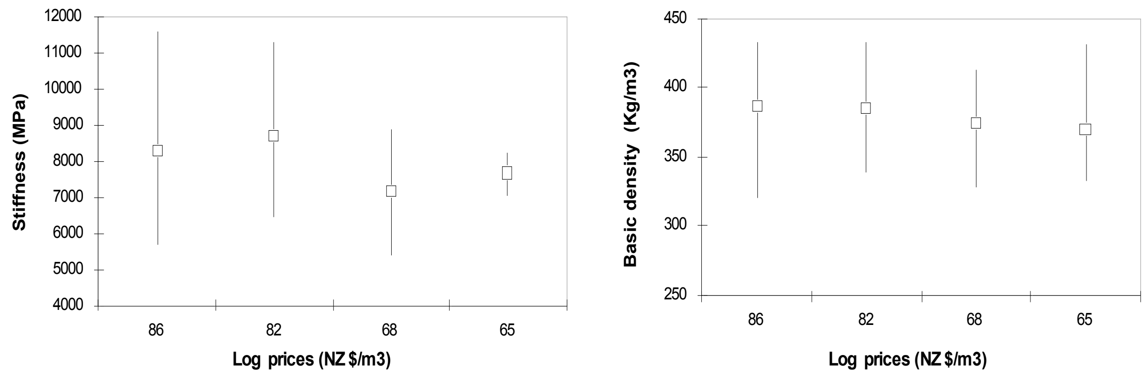
Table 3: Classification, prices and conversion return of logs.

Log classification*	S1	S2	L1 & L2	S3 & L3
Number of logs	13	25	33	3
Market price (NZ \$/m^3)	86	82	68	65
Conversion return (NZ \$/m^3)				
Average	125	126	78	72
Maximum	234	210	151	138
Minimum	-20	-1	1	8

*Source Ministry of Agriculture and Forestry (MAF), New Zealand 2008

Log prices should reveal the processors' willingness to pay for wood stiffness and density, especially when considering the importance of those traits in the quality of structural timber. The lack of incentives to improve logs' attributes could lead to a market with a lower participation of high quality logs than when pricing logs according to wood quality.

Assuming that we are working with a representative sample, the incentive for growers to produce the best structural log is 21 NZ \$/m^3. This value corresponds to the difference between the price of S1 and S3 logs. However, for processors the average difference on recovery value between those logs was 53 NZ \$/m^3, increasing up to 96 NZ \$/m^3 for the highest quality logs. Processors have more incentives to purchase these logs than the growers to produce them and without incentives processors will continue receiving the highest quality logs only sporadically.



a) b)

Figure 1. Stiffness (a) and basic wood density (b) variability and corresponding log prices.

The importance of BDENS and STF to define wood quality and log value is corroborated by the correlations between CR and log attributes (Table 4). The highest correlations were between CR and STF, and CR and BDENS. On the other hand, the association between CR and SED was negative and non-significant. In contrast, the correlations of CR with BI and LB presented the expected signs but with coefficients lower than 0.5. A similar trend has been documented by Cotterill and Jackson (1985).

Table 4. Pearson correlation coefficients for conversion return (CR)

Correlations	Stiffness	Small end diameter	Branch index	Largest branch	Basic density
CR	0.85**	-0.28*	-0.45**	-0.43**	0.69**

*Significant at 0.05 level; **significant at 0.01 level.

Hedonic price models. First regressions with dummy variables were run to detect differences of STF, SED, BI, LB and BDENS between second and third logs. Dummy variables related to slope and interaction were not significant. Accordingly, the hedonic model considered all 71 logs, with predictors SED, STF, BD, BI, LB and TP (see table 5). The variables presented the expected behaviour in relation to log value, except for TP. TP showed a positive but non-significant relationship with log recovery value. This unexpected tendency was also observed in the correlation between TP and SED. SED and STF were the most important variables for predicting quality and value of logs for structural timber, accounting for 73% of the variation in CR.

Table 5. Parameter estimates: hedonic models for logs' wood attributes.

Model 1	Trait	Parameter	Standard error	R^2-adj
β_0		-303.003**	50.589	0.75
β_1	SED	0.112*	0.048	
β_2	STF	0.029**	0.005	
β_3	BD	0.365*	0.187	
β_4	TP	2.310*	1.097	
β_5	BI	-0.549*	0.254	

*Significant at 0.05 level; ** significant at 0.01 level.

Regarding hedonic prices, the value of SED was 0.11 NZ $/mm, which represents the marginal contribution to CR for having an extra millimetre of SED. Hedonic prices of log traits showed the expected signs, with the exception of TP.

BI presented a negative hedonic price due to the effect of knots on stiffness. In contrast, Alzamora and Apiolaza (2009) reported a positive hedonic price for BI in a study about logs for producing Factory lumber. This result was explained by the positive correlation between BI and commercial volume, and between BI and internode length. The sign associated to BI could be different if there were stiffness requirements for Factory lumber.

In addition, Alzamora and Apiolaza (2009) reported a hedonic price for SED three times higher than the value obtained in this work. Having a large SED is considered an advantage due its direct relationship with lumber yield. However, in the current work SED was negatively correlated with MSG8+ volume, because of its negative correlation between SED and stiffness. In this way, the economic value of SED would depend on the trade-off between yield and quality of the lumber. If prices reward lumber stiffness, SED would have a lower weight than in a situation where stiffness was not considered.

Green density was not included in the models because it was already used to estimate STF, and could generate collinearity problems.

Efficiency analyses. The purpose of using DEA was to have some degree of validation of the results obtained in the section of hedonic prices. We expected technical efficiency (TE) and cost efficiency (CE) to be highly correlated with CR and hedonic prices of wood traits. The estimation of the efficiency indices considered one product, which was the sum of all MSG8+ volumes by log. A threshold of 8 GPa is commonly used to qualify radiata pine timber for structural issues (Chauhan 2006). The wood characteristics used as inputs were SED, BDENS, and STF. However, CE also required information about input prices, for which we used the hedonic prices estimated in the previous section.

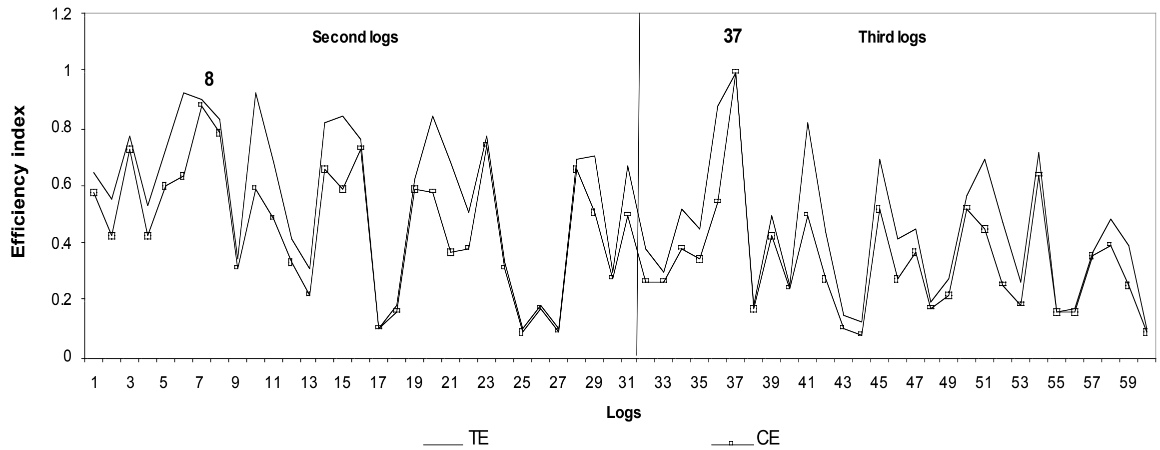


Figure 2. Technical efficiency (TE) and cost efficiency (CE) by log.

TE reflects the ability of a log to generate maximum output from a given set of inputs (Coelli et al. 2005). Log number 37 is the log with highest TE and also presents the highest score on CE; thus, this log would qualify as fully efficient. Nevertheless, these scores are relative values; therefore they are highly dependent on the sample. We added a fictitious log to the sample to corroborate the relativity of the efficiency analyses. This log has the same attributes values of log number 37, except for a 5% more of MSG8+ volume. As expected, this log had the highest TE and CE and all other individuals obtain their efficiency scores in relation to the new top log. The efficiency score also depends on the product that is being evaluated. Thus, if the timber MSG10+ is considered, the ranking favors a second log. Details of log number 37 are presented in table 6.

Table 6. Wood attributes and log values for logs 37 and 8.

Log	No	SED (mm)	BDENS (kg/m^3)	Stiffness (MPa)	BIX (mm)	Price (NZ $\$/m^3$)	Log CR (NZ $\$/m^3$)
3rd	37	506	386	8038	64	68	151
2nd	8	483	401	8046	45	86	153

We considered a less efficient second log (number 8) to further explain the concept of efficiency. This log has a TE of 0.83 which means that its inputs could be diminished by 17% and still it would be able to achieve the same output of MSG8+ (0.329 m^3). Improving TE implies that the log will move to the efficiency frontier because it will able to generate more output with the available inputs –product maximization. Similarly, finding an efficient input mix (given the input prices) will imply a movement along the frontier up to the optimal point– cost minimization. The most efficient log (number 37) corresponds to a third log with the highest difference between market price (NZ\$ 68/m^3) and CR (151 NZ \$/m^3). This is an interesting result considering that neither information of conversion return or log prices are included in the TE analysis. In addition, in the current market scenario log number 37 would be highly convenient for processors but not for growers, but none of them are able to notice this situation.

Conclusions

The objective of this study was to find economic values of log attributes for the production of structural timber in New Zealand. Those values were estimated using hedonic models. The signs of the hedonic prices were negative for BI, but positive for SED, STF and BD. These models considered the log CR instead of the log price as dependent variable. Using CR allowed valuing the marginal changes on wood traits, which is important for a proper application of hedonic models.

The comparative analysis between log prices and CR showed that every log price class is including a wide range for STF and BDENS. This is one of the main reasons to prefer CR over log prices to fit hedonic models. In addition, there were some logs classified as S1 and S2 that presented negative CR, which demonstrates an incompatibility between the value of the wood quality contained in the logs and the current log price system. However, this was only evident for the most expensive logs (S1 and S2).

The application of the efficiency analysis using DEA was useful to have an alternative approach to breeding wood quality in logs. DEA analysis offers a perspective based on attribute mixes that generate efficient solid timber production at the log level. This analysis suggests that stiffness and wood density should guide log segregation for structural timber; whereas log diameter and branch size do not have enough relevance to discriminate quality and prices for structural logs. This result is contrary to the current log classification protocols; however, the pertinence of updating logs segregation systems has been already stressed by other authors. The cost efficiency analysis that used hedonic prices produced coherent results about which logs were more efficient from an economic point of view.

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