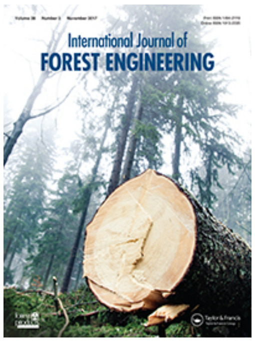

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Harvesting contractor production and costs in forest plantations of Argentina, Brazil, and Uruguay

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ABSTRACT

Timber production from forest plantations has increased substantially in South America in the last few decades. The timber harvesting process is carried out mainly through logging contractors. This research developed production and cost 'functions for logging contractors working in Misiones and Corrientes (Argentina), Paraná, Santa Catarina and Rio Grande do Sul (Brazil) and Uruguay. Data were obtained from surveys: 22 in Argentina, 35 in Brazil and 10 in Uruguay between 2008 and 2012. When considered as a share of the total production region, we sampled a weighted average of 21% of the firms, which means an annual production of 17.7 million cubic meters. Regressions of the variables species, operations, contractors and mechanization indicated that the logging costs per ton were higher in Uruguay, as were logging contract prices. The contract prices paid for thinning were significantly higher than those of clearcutting, but average logging costs did not differ significantly. A large amount of capital was needed to begin operations, but there was an inflection in the average cost curves at 50,000 tons/month, and average costs were asymptotic at 100,000 tons/month. Logging contractors working for pulp companies have significantly higher capital value and the largest payroll. The fully mechanized logging firms had the highest capital costs. The Cobb-Douglas function was best to estimate production and cost models. Last, the size of the logging firms in these three countries was larger than those reported for southeastern USA and for Scandinavia. However, average costs were not as low as reported in those countries.

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Introduction

The forest industry has grown consistently in recent years, and much of this growth has been focused in the Southern Cone countries such as Argentina, Brazil and Uruguay. Like any global industry, forest production and harvesting are driven by costs. The development and competitiveness of companies have been based in factors like low production costs, excellent plantation growth, as the availability of large areas for afforestation (Barnden & Orlando 2007; ABRAF 2009; Cubbage et al. 2010).

Forest harvesting comprises about 50–70% of total roundwood production and transport costs to industries (Díaz & Mac Donagh 2001; Laroze 2001; Siry et al. 2003; Stein do Quadros and Malinovski 2012; Berg et al. 2014). Production costs have changed over time. Better knowledge of these costs can help producers and forestry companies assess the merits of different countries and the factors that influence costs. Increased mechanization is expected to decrease costs, but little empirical data exist in South America. At the regional or country level, there are many actors, including forest companies, logging contractors, and harvesting machines dealers and manufacturers. Mechanization usually, but not always, has meant larger machines, more production capacity, and less cost. Thus, logging cost studies are quite complex and the amount of research in Latin America is sparse, although there is more published research in other regions like United States and Europe, or New Zealand (Dodson et al. 2015; Di Fulvio et al. 2017; Okey and Visser 2017).

In southeastern USA, Cubbage and Duncan (2001) reviewed logging costs by technological class between 1979 and 1988. The average cost per unit of volume was generally much cheaper for tree length systems, in 1979 and in 1988. The average cut-to-length systems costs were stable between 1979 and 1988, at US$ 21 to US$ 22 per m^3, indicating little increase in the efficiency of these systems. However, average costs per cubic meter fell $4 per m^3 for highly mechanized tree length systems, from $16 to $12 per m^3 during the period. This rapid increase in cost efficiency was reflected in major changes in those systems. The highly mechanized feller-buncher grapple-skidder systems comprised only 35% of all timber harvesting in 1979, and 71% in 1987. The capital-intensive systems were more cost-efficient in both periods, and decreased in costs in 1987. Small-scale technology and equipment was less efficient in the 1980s, which probably continues to be the case.

In Georgia, USA, Greene et al. (2001) also reported trends in weekly production for individual companies from 1987 to 1997. The average production increased from 600 m^3 per week in 1987 to 1020 m^3 per week in 1992 and 1180 m^3 per week in 1997. The number of employees per crew from 1987 to 1997 increased from 5.96 to 6.61, and the volume produced

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per man-hour grew from 2.5 to 4.5. Finally, the capital value per company grew from US$ 244,000 to US$ 493,000. In contrast, in North Carolina, by 2001, harvesting contractors high production produced up to 1700–2100 cubic meters per week (Cubbage & Duncan 2001).

Baker and Greene (2008) conducted a study of harvesting contractors in Georgia (USA), every 5 years for a 20-year period from 1987 to 2007. The average weekly production per company increased 83% since 1987, and this increase was significant ($p = 0.05$). A moderate increase (about 15%) in the share of fully mechanized harvesting equipment was detected, with increased investment, but with diminishing returns. In this period, the average production per man-hour increased by over 50%. The largest contractors at the beginning of the study remained so at the end, and the smallest decreased in size. The feller-buncher grapple-skidder system had the strongest growth, increasing from 70% in 1987 to 80% of the systems in 2007. Baker and Greene also found a significant increase in productivity – from 3.95 tons per man hour in 1987 to 6.2 in 2007.

Stuart et al. (2010) conducted a study on harvesting contractors in 12 southern USA States, between 1998 and 2007. They found that harvesting firms changed their business strategies and spending priorities each year to accommodate business changes. The expenditure categories varied greatly over time. The greatest variations in costs were observed in smaller companies with annual output of 75,000 tons. In larger companies, this variation tended to decrease with increased production. The data indicated that production levels of contractors changed significantly during the study period.

In Santa Catarina Brazil, Stein do Quadros and Malinovski (2012), conducted an analysis between mechanized and semi-mechanized harvesting companies. They found that only the fully mechanized companies had average costs returns that yielded a break-even profitability. The semi-mechanized system needed to work above its stated capacity to reach the break-even profit levels.

In the Brazilian forestry sector, 70% of the forest harvesting services were performed by contractors (Leite 1999). In about 2000, there were about 100 contractors with more than 10,000 employees (Fernandes 2002). In the countries with the most developed forestry sector, such as Finland, Sweden and Norway, logging contractors began to become common in the 1970s, and their share has grown dramatically since then and accounts for 75% of harvesting operations (Hultaker and Bohlin 2004).

In Uruguay, forestry activities are more recent, although there are large companies with extensive woodlands working with harvesting contractors (Mendell et al. 2007). In Argentina, the trend is to outsource harvesting, and large companies are the ones that have adopted this trend (Díaz & Mac Donagh 2001; Martinelli 2001; Mac Donagh & Cubbage 2006).

The highly mechanized system requires some special conditions to be successful, such as: investment in harvesting equipment; ease of access for loans; fast and efficient equipment maintenance; reasonable operating costs; availability of skilled operators, and production contracts that match with the logging company capacity (Binda 2002; Bravo Cerda 2004; Alves 2006).

Various methods have been used to develop timber harvesting production models and cost models. The first basically considered capital and wages, with information coming from logger surveys or secondary data from logging association reports (Carter et al. 1994; Cubbage & Duncan 2001; Okey & Visser 2017), contractor surveys for cost indices (Stuart et al. 2010), or questionnaires (Baker & Greene 2008; Stein do Quadros & Malinovski 2012). The cost models developed considered the type of harvesting system and technological changes through time. But most do not include factors like type of contractors company, type of operations, species, and differences between countries or regions.

Prior studies found that mechanization resulted in the more efficient use of labor and improved productivity. Large firms significantly decreased average costs, so there are increasing returns to scale in the logging sector, and a substantial decrease in average harvesting costs. However, Baker and Greene (2008) and Stuart et al. (2010), indicated that marginal returns on invested capital modern mechanized logging operators continued to decline despite substantial increase in production.

This research analyzed contractors through production and cost models of harvesting plantation systems in Argentina, Brazil and Uruguay. Multiple regressions and Cobb-Douglas function models were developed, with the objective to explain the factors that affected production, costs, and returns to scale of logging contractors. This is perhaps the first published research that has analyzed logging production and costs across several countries, based on detailed surveys and personal interviews to collect primary data from many firms. The resulting excellent data and subsequent analysis allowed us to make substantial improvements in the results for South America. We focus on logging contractors in each country and their relations with contract firms, species, operations, and mechanization level.

Materials and methods

Data for this this study were obtained for the mechanized harvesting contractors working in timber plantations in three countries of the Southern Cone: Argentina (Misiones and Corrientes Provinces); Brazil (Parana, Santa Catarina and Rio Grande do Sul States), and Uruguay.

The study period was carried out between years 2008 and 2012 with personal interviews made by the lead author, which captured the strong mechanization process that happened in these three countries. Contractor surveys were conducted through interviews with the company's owner/manager. All the interviews used the same questionnaire, which provided the data for the models described below. This covered production, costs, the level of mechanization, species, type of operation, type of contracting, and country. This is perhaps the first study that has reported logging production and costs within these three countries as based on detailed surveys and personal interviews conducted with several logging businesses

Individual firm costs

In this work, the Food And Agriculture Organization of the United Nations (FAO) costs methodology was adopted (Boltz et al. 2003; Holmes et al. 2002), which divide costs into fixed, semi-fixed and variable costs. The use of this methodology – similar to prior studies – allowed us to obtain comparable data and analyses, and avoid biases such as the influence of the age of the equipment, levels of breakage, or other more specific questions of each firm. The average harvest costs were estimated for each company, then these costs were added by harvesting system, by sector and by country. Total costs per firm averages were calculated as shown below in Equation (1):

$$CTP = \left(\sum_{i=1}^{n} P_i X_i + \sum_{i=n+1}^{n+k} P_i X_i\right)/q \tag{1}$$

where:

CTP = Total average cost per company;

P = price of the input factor (equipment, labor, production factors);

X = the quantity of the input factor;

i = the individual firm, 1 to n = fixed costs (depreciation, interest, taxes, insurance, management, supervision, owners);

n + 1 to n + K = the variable costs (fuel, lubricants, piecework wages);

q = quantities produced in tons per month.

These individual costs per firm when aggregated estimate the components of the sectors of each country. They were used as individual data to compose average harvesting costs and thus make statistical comparisons between species, operation, mechanization, contracting and countries, using tests such as Tukey mean differences at 0.05.

Production and cost functions

Production functions were estimated according to the classical models of Carter et al. (1994); Cubbage and Duncan (2001); and Stuart et al. (2010). These models use capital and wages to predict production and costs. Then "dummy" variables were employed to delineate the effects of species, operation, contractors, mechanization level and countries. Two functions were adapted from Carter et al. (1994) – a quadratic one, and a log/log, also known as the Cobb-Douglas model.

Both forms are inflexible because they have several restrictions on technology. For example, the linear function assumes that capital and labor are perfectly substitutable in production, while Cobb-Douglas function assumes a constant unit elasticity.

The models used were:

Simple quadratic:

$$P = \beta o + \beta 1C + \beta 2S + \beta_i D_i 1 + \tag{2}$$

Log/Log:

$$lnP = \beta o + \beta 1lnC + \beta 2lnS + \beta_i D_i \tag{3}$$

where P is monthly production in tons; C, capital in US$, expressed as depreciation; S, operator wages per month; D_i is a dummy variable to assess the effect of the species, operation, contracting, equipment spread, and region; and ln = natural logarithm. The coefficients β1 and β2 are the marginal products of capital and labor respectively. β_i is the intercept for the shift in the cost curve dues to the dummy variable. The dummy variables considered were species, type of operations, level of mechanization, country, and contracting companies.

Thus, for the country dummy variable Argentina was held constant and the effects of Brazil and Uruguay were tested. For species, the dummy variable for Eucalyptus was held constant, and the effects of Pinus, and companies working with both species were examined. To evaluate the effect of operations, thinning was held constant, and effects of clearcuts and effects companies working in both thinning and clearcuts was evaluated.

To evaluate the effect of contracting companies, the sawmills were the base effect, and pulp companies were the dummy variable. To evaluate the mechanization effect, fully mechanized firms (feller-skidder, harvester-forwarder) were held constant the full and the semi-mechanized effects were evaluated with the dummy variable.

Then regression analysis was used to estimate cost functions (Carter et al. 1994; Siry et al. 2003; Bauch et al. 2007), adding "dummy" variables for each region or sector.

Results

In total, 67 logging contractors were interviewed, with 22 were from Argentina, 35 from Brazil, and 10 from Uruguay (Table 1). The sample of companies produced an average of 17.7 million cubic meters per year, which represented 21% of the total production of all logging companies in the three countries (83 million cubic meters per year). In all three countries, the greatest roundwood demand came from cellulosic (pulp and paper) companies. Sawmills, and medium enterprises, are more important in Argentina (35%) than in Brazil and Uruguay.

Table 1. Volume produced by 67 logging contractors within the three study areas during the survey period and their annual production (cubic meters).

	Country			
Factor	Argentina	Brazil	Uruguay	Total
Saw timber	1,302,720	1,525,200	444,000	3,271,920
Pulpwood	2,292,000	9,517,293	2,635,200	14,444,492
Total during survey period	3,594,720	11,042,492	3,079,200	17,716,412
Total annual production	8,000,000	67,292,252	8,000,000	83,292,252

Where: Argentina: provinces of Misiones and Corrientes; Brazil: States of Paraná, Santa Catarina and Rio Grande do Sul.

Table 2. Benchmarking among surveyed countries. Summary of minimum wage, diesel fuel cost, interest rate, exchange rate, and purchase price for a Caterpillar 320 excavator in the three countries.

Country	Minimum wage (US$/month)	Gas Fuel (US$/l)	Interest rate (%)	Exchange rate	CAT 320, purchase price (US$)
Argentina	464.65	0.93	15	4	193,000
Brazil	318.18	0.86	15	2.2	192,000
Uruguay	300	1.39	5	20	180,000

Where: Argentina: provinces of Misiones and Corrientes; Brazil: States of Paraná, Santa Catarina and Rio Grande do Sul. Exchange rate: Average currency exchange from each country Central Bank with the US dollar. Source: Authors.

Macroeconomics and product demand

Even though Brazil, Argentina, and Uruguay are different countries, forest production conditions are similar. However, the macroeconomic context was different. Argentina and Brazil were not as economically stable as Uruguay (Cubbage et al. 2014). Table 2 summarizes selected benchmarks among the countries with indicators such as interest rates, minimum wage, and exchange rate and machinery prices. Each are discussed below.

The fuel price was computed as the average of surveys in each region. The highest price was in Uruguay because the fuel is not subsidized, as in Argentina, and Uruguay imports all the fuel it consumes. The interest rate reflects the average rate reported by contractors when they bought equipment. This includes both local bank fees, leasing obtained from manufacturers and their own rates they assign to owned capital.

As a typical feller-buncher, we used the Caterpillar 320 excavator, one of the most common machines in the three countries. The purchase price data were obtained with contractors through surveys. Since the data collection period lasted from 2009 to 2011, some price differences occurred, for example by changes in tax conditions for imports, mainly in Argentina and Brazil. However, it was much cheaper and easier to import harvesting equipment in Uruguay than in Argentina and Brazil.

Large pulp and paper companies lead the forest economy and logging contracts in each country. These companies usually drive technological change, rapidly boosting mechanization, or other changes in logging firms. We categorized monthly production in tons for subsequent analysis, since it is the most commonly used metric in this forest sector. Based on the production data, we classified (a) large companies, those who consume more than 100,000 tons/month, i.e. over one million tons per year; (b) medium firms from 20,000–100,000 tons/month, which would be MDF industries, large sawmills, or large plantations owners that sell roundwood; and (c) small firms as those below 20,000 tons/month (Table 3).

Brazil has the largest pulp firms. In fact, they are the largest forest country by far of the three regions analyzed. Accordingly, they have the largest logging companies and a higher mechanization level. In Argentina, there is only one pulp company and a large plantation owner harvesting over 100,000 tons/month. The rest are medium enterprises, mainly represented by sawmills. In Uruguay, there are two pulp companies, one much larger than the other; then there are important medium firms as one veneer manufacture, sawmills and chipping firms for export. In all three countries, cellulosic paper companies purchased the most timber, accounting for 83% of total demand.

Cost functions

The influence of independent variables like species, operation, contractors and mechanization on the dependent variable of total or average costs are presented in Tables 4 and 5. Total costs per firm were significantly higher in Uruguay than Argentina and Brazil. The average cost per ton was also higher in Uruguay. The directional impact of the factors of production for logging firms was similar in all the countries. The factors of species, type of harvesting operation, and mechanization did not produce significant differences for total cost or cost per ton. Logging contractors that work for pulp companies were larger than those that work for sawmills in any country. Mechanized logging firms did not show cost differences compared with half mechanized, but had significantly larger production. Taxes were lower in Argentina. Uruguay had better logging contract prices, but negative profits due to the higher costs. In this case, it is noteworthy that the machine spread in Uruguay is much newer than in other regions, with more recent mechanization, so its capital costs were higher.

The largest logging firm production levels were in Brazil. In Argentina, no company produced more than 50,000 tons per month, while in Brazil four of 35 companies evaluated exceeded 50,000 tons, and Uruguay only one out of 10. A logging company that produced more than 50,000 tons per month could be near the marginal cost inflection point of achieving diminishing increases in total costs, or asymptotic average costs (Table 5).

While Uruguay had negative profit margins, their higher contract rate helped offset higher costs, but losses could not be sustained in the long run. Firms in Uruguay had

Table 3. Number of companies and percentage of volume produced by large, medium and small contracting companies by country.

Country	Large		Medium		Small		Total production (T month^{-1})
Argentina	2	(78%)	4	(21.5%)	1	(0.5%)	299,560
Brazil	10	(89%)	8	(8%)	8	(2%)	904,426
Uruguay	2	(68%)	6	(30%)	1	(2%)	256,600

Where: Argentina: provinces of Misiones and Corrientes; Brazil: States of Paraná, Santa Catarina and Rio Grande do Sul Source: Authors, based on the surveys.

Table 4. Analysis of variance results for total costs, capital expenses and wages of logging firms by country (US$/month).

	n	Cost	SE	*p*	Capital	SE	*p*	Wages	SE	*p*
Country				0.006			0.39			0.15
Argentina	22	91,689	46,643		754	540		32,252	12,492	
Brazil	35	159,644	36,980		1505	428		47,306	9904	
Uruguay	10	**366,541**	69,182		1958	801		76,809	18,528	
Species				0.003			0.01			0.08
Pine	28	127,300	42,468		1087	451		36,239	10,962	
Eucalyptus	30	151,542	41,028		842	436		44,434	10,590	
Both	9	**351,048**	74,906		**3679**	796		87,290	19,335	
Mill type				0.01			0.05			0.00
Sawmill	29	82,558	41,284		628	456		22,157	10,362	
Pulp	38	233,577	36,066		1858	402		65,547	9052	
Operation				0.01			0.01			0.08
Thinning	14	100,742	58,355		757	636		38,242	8850	
Clearcut	43	141,294	33,297		987	363		40,500	15,510	
Both	10	378,409	69,047		3580	753		85,644	18,352	
Mechanization				0.00			0.01			0.02
Half mechanized	20	45,335	49,283		174	545		20,921	8376	
Fully mechanized	47	220,498	32,149		1816	355		57,764	12,840	

Numbers in bold mean significant differences by Tukey HSD at p = 0.05; SE, standard error. Values in thousands of dollars

Table 5. Analysis of variance results for cost, taxes, prices, production, and profit margin in the three countries (US$/ton).

	n	Cost/t	SE	*p*	Taxes	SE	*p*	Contracting price	SE	*p*	Monthly production (t)	SE	*p*	Profit margin	SE	*p*
Country				0.00			0.01			0.00			0.54			0.14
Argentina	22	7.41	0.89		**0.65**	0.15		8.66	0.78		13,616	9167		0.76	0.55	
Brazil	17	8.19	0.71		1.24	0.12		9.68	0.62		26,292	7268		0.97	0.44	
Uruguay	10	**14.82**	1.32		1.24	0.23		**13.64**	1.16		25,660	13,598		−0.87	0.82	
Species				0.71			0.92			0.7			0.50			0.87
Pine	28	8.35	0.92		1.01	0.26		9.86	1.34		16,827	14,318		0.78	0.88	
Eucalyptus	30	9.31	0.89		1.02	0.14		9.70	0.76		22,644	8117		0.44	0.48	
Both	9	9.44	1.63		1.09	0.14		10.97	0.73		36,211	7842		0.78	0.50	
Mill type				0.67			0,05			0.48			0.03			0.79
Sawmill	29	8.63	0.90		0.84	0.14		9.54	0.74		9402	7725		0.72	0.49	
Pulp	38	9.15	0.79		**1.20**	0.12		10.24	0.65		**31,677**	6749		0.56	0.43	
Operation				0.50			0.60			0.02			0.38			0.89
Thinning	14	8.43	0.74		1.18	0.12		11.47	0.58		11,607	6521		0.78	0.71	
Clearcut	43	9.53	1.30		0.97	0.24		8.95	1.02		22,046	11,428		0.52	0.40	
Both	10	10.22	1.53		1.16	0.20		**12.03**	1.20		36,590	13,522		0.89	0.84	
Mechanization				0.77			0.55			0.51			0.04			0.54
Half mechanized	20	8.82	0.71		1.01	0.11		9.44	0.58		5424	9315		0.32	0.59	
Fully mechanized	47	9.18	1.09		1.13	0.17		10.15	0.89		**29,104**	6076		0.76	0.38	

Numbers in bold mean significant differences by Tukey HSD at p = 0.05; SE, standard error.

much less business experience, which results in lower efficiency. All the major logging cost components were more expensive in Uruguay, including equipment depreciation, wages, fuel, and administration. One would expect that profitability would increase in the long run, or loggers would drop out of business. Uruguay also might shift more to grapple-skidder feller-buncher systems if they prove to be cheaper there than the harvester-forwarder systems.

Looking at individual cost factors by the other breakdowns by species harvested, sawmill/pulp contracting, thinning/clearcut operation, or mechanization level, there were no statistically significant differences in costs per ton, and indeed no striking differences in the averages by input factor (Table 6).

Logging firms working for pulp contractors were significantly larger, regardless of the region under consideration. The same applies to the monthly payroll, capital, and the monthly cost. However, larger firms did not have lower costs per ton, or higher margins, although average contract prices were US$ 0.7 per ton higher with cellulosic companies than sawmills.

No significant differences for the costs per ton were found for the type of harvest operation. This is important, because normally the thinning operation is associated with higher costs, but not within the companies studied. The lowest prices were for clearcutting, while thinning was US$ 0.26 per ton greater, although it was not significantly different statistically

The firm size measured by production and capital was associated with more mechanized production, and more wages, although not necessarily more employees. However, more mechanized companies did not exhibit significant differences in the cost per ton than less mechanized. Contractors also had different prices by the level of mechanization. The profit margins were not significantly different, although fully mechanized logging firms were on average 0.44 US$/ton more than the non-mechanized.

Harvesting systems

Felling methods differed across the three countries with feller bunchers most common in Argentina, use of processors (Excavator machine with harvesting head processing trees at the landing area) most common in Brazil, and use of

Table 6. Summary of individual firm costs according to the FAO cost methodology (Boltz et al. 2003; Holmes et al. 2002) (US$/ton).

	n	Fix	SE	p	Depreciation	SE	p	Wages	SE	p	Fuel	SE	p	Adm.	SE	p
Country				0.51			0.00			0.00			0.00			0.000
Argentina	20	0.34	0.05		1.34	0.21		1.16	0.33		1.86	0.38		1.36	0.17	
Brazil	12	0.43	0.07		1.74	0.27		1.15	0.43		3.35	0.49		1.68	0.23	
Uruguay	9	0.35	0.07		**3.16**	0.31		**2.14**	0.49		**6.56**	0.57		**3.25**	0.26	
Species				0.93			0.34			0.39			0.24			0.316
Pine	22	0.37	0.05		1.63	0.25		1.24	0.33		2.78	0.52		1.67	0.23	
Eucalyptus	10	0.38	0.07		2.34	0.37		1.71	0.49		4.38	0.78		2.30	0.34	
Both	9	0.34	0.08		1.85	0.39		1.33	0.52		3.49	0.82		1.87	0.35	
Mill type				0.52			0.77			0.29			0.13			0.489
Sawmill	17	0.39	0.06		1.77	0.29		1.20	0.37		2.62	0.59		1.73	0.29	
Celullosic	24	0.34	0.05		1.91	0.24		1.50	0.31		3.82	0.50		1.97	0.24	
Operation				0.25			0.76			0.69			0.64			0.512
Thinning	10	0.45	0.07		1.76	0.26		1.58	0.48		2.96	0.80		1.94	0.38	
Clearcut	21	0.32	0.05		1.79	0.38		1.28	0.33		3.19	0.55		1.69	0.38	
Both	10	0.37	0.07		2.09	0.38		1.36	0.48		3.97	0.80		2.17	0.26	
Mechanization				0.21			0.89			0.40			0.76			0.126
Half mechanized	2	0.56	0.16		1.92	0.83		1.89	1.04		3.87	1.78		3.00	0.74	
Fully mechanized	39	0.35	0.04		1.85	0.19		1.35	0.24		3.30	0.40		1.81	0.17	

Numbers in bold mean significant differences by Tukey HSD at $p = 0.05$; SE, standard error; Fix, fixed cost; Adm, administrative cost.

Table 7. Harvesting equipment configuration reported by contractors in the three countries.

	Argentina	Brazil	Uruguay	Total
Felling				
Harvesters	35%	5%	60%	40
Fellers	48%	39%	13%	23
Processors	20%	57%	23%	91
In-woods transport				
Forwarders	17%	25%	58%	48
Grapple skidders	47%	45%	8%	38
Agricultural tractors	51%	20%	30%	81

harvesters most common in Uruguay. In Uruguay, the harvester forwarder system has been widely adopted, basically for clearcutting Eucalyptus. This system is similar to that used in Scandinavia, where the parent companies in Uruguay are located. Argentina differs between thinnings and clearcuts. For Pinus clearcuts, the most frequent system is a feller buncher system of both track and wheel grapple skidders, and then processors. In pine thinnings, although there are still operations with chainsaws, the most frequent are both small wheel harvesters, as well as small processors (Table 7).

Despite these generalizations, the survey responses indicated that the companies still had a variety of equipment configurations. For example, the larger harvesting companies, which had several mill customers, maintained several configurations at the same time. Thus it was not possible to establish one harvest system for each company, but each developed a system by type of harvest operation, often agreed with the contractor.

Production and cost modeling

We modeled production, total cost, and average cost functions for the logging contractors for all countries and cost components (Table 8). The combined quadratic production models for all countries and input factors showed that wages were the most significant contributors to output, and when the dummy were considered, the loggers from Uruguay showed significantly less production than the other two countries. This was corroborated with the forward stepwise regression model, which showed that after the wage, Uruguay was the most significant contributor of the model variables. As expected, when the Cobb-Douglas form was considered, the model indicators improved. In this case, capital had greater elasticity than wages, and was statistically significant, unlike quadratic models.

Carter et al. (1994) also found that capital and wages were significant when employed in Cobb-Douglas function. However, the statistical significance found by these authors was less than those in our study. Capital had a greater elasticity (0.89) for the highest level of mechanization in Carter et al., compared to 0.53 found here. It should be noted that capital was determined differently in Carter et al. (1994) and Bauch et al. (2007). While the first is based on secondary industry surveys, the second is based on a equipment value estimate based on the age of the equipment.

In our study, the capital estimate was obtained based on the market value of each team, and the intensity of use assigned by each contractor. In addition, over 90% of respondent contractors acquired their machines with credit or leasing, thus, this rate was used in the calculation of the value of capital. Thus our value of capital should be more accurate than that only considering age (Bauch et al. 2007) or the statements in secondary industry surveys (Carter et al. 1994). Finally, the coefficient of determination of the Cobb-Douglas models found were higher than those reported by Carter et al. (1994), and much higher than those of Bauch et al. (2007).

According to the models developed, there were constant production increases of assets of up to more than US$ 250,000, which corresponded to the largest contractors in

Table 8. Selected production function, total cost, and cost per ton models for Argentina, Brazil, and Uruguay, using quadratic and Cobb-Douglas log functions.

	r^2	p
P = −9731.02 + **0.79S**** −32,389.**4Uy**** −3.63K +14,124.03TR	0.75	0.000
LnP = 1.29 + **0.55LnK**** + **0.45LnS**** − **0.60Uy**** + 0.24TR −0.29Br	0.85	0.000
C = −22,744.25 + **10.47P**** − **0.000021P2**** + **186,548.03Uy**** −81,544.**92R/TR**** + **89,884.77Mec**** + 49,482.38Pi	0.89	0.000
Ln C = **10.87**** −9.**04Br**** − **8.28Uy**** + **0.39Cel*** − 0.28R/TR+0.21Pi	0.99	0.000
C/t = **8.36**** + **11.18Uy**** + **6.87Mec**** − **3.29 R/TR**** + **4.55Br**** − **0.00011P*** + **0.0000000003P2*** +2.01Cel	0.62	0.000
Ln C/t = −2,01 + **10.07Br**** + **10.56Uy**** + **0.43LnP**** + 0.63Mec − 0.19TR	0.99	0.000

C/t, cost per ton US$ t^{-1}; P, production in ton per month; C, firm cost per month in US$; K, capital in thousands of US$; S = wages in US$ per month; Pi, pines; Eu, Eucalyptus; R = thinning; TR = clear cut; Cel, cellulosic firm; Mec, mechanization; Br, Brazil; Uy, Uruguay. **Bold**, ** significance at 0.001; and * at 0.05. The dummy base were: Argentina, Eucalyptus, thinnings, sawmills, and mechanization.

these three countries. However, these proportional increases in scale were not constant. When the residual distribution of both types of models is observed, it is confirmed that the Cobb-Douglas model is more parsimonious. In turn, the Furnival Index (Crechi et al. 2006), was much smaller for the logarithmic model than for quadratic (42,187 to 110,497, respectively) (Figures 1 and 2).

We discuss the harvesting cost model results here next. The quadratic total cost models showed statistically significant contributions by the production level, and the dummies for Uruguay, both operations, and mechanized logging firms (Table 8). The Cobb-Douglas models improved the coefficient of determination, and showed negatives intercepts for Brazil and Uruguay, and there appears a significant effect of cellulose industries as contractors. Thus, it is clear that Uruguay is different in the total cost model, and also depending on the model choice, mechanization or cellulose contracts had an effect on total cost. Thus, larger logging companies, those which are mechanized or working for cellulose companies, probably will be more efficient, between 50,000 and 100,000 tons by month, where the models show a shift in the slope of the curve.

There were decreasing costs with increasing production, which is also related to the return to scale concept, where larger companies spread out their fixed costs more than smaller companies. The higher level of production for larger firms lowered the average cost of harvest. This fact is also matched when the dummy variables as the pulp contracting companies and mechanization were incorporated (Figures 3 and 4).

When the total cost increase was analyzed, from 50,000 tons per month, the monthly cost curve increase slowed considerably, indicating the dilution of fixed costs. Firms were more cost-efficient due to the returns to scale. Starting at 25,000 tons, the rate of increase in cost was around 4%, and at 50,000 tons, it was about 2%. At the beginning of

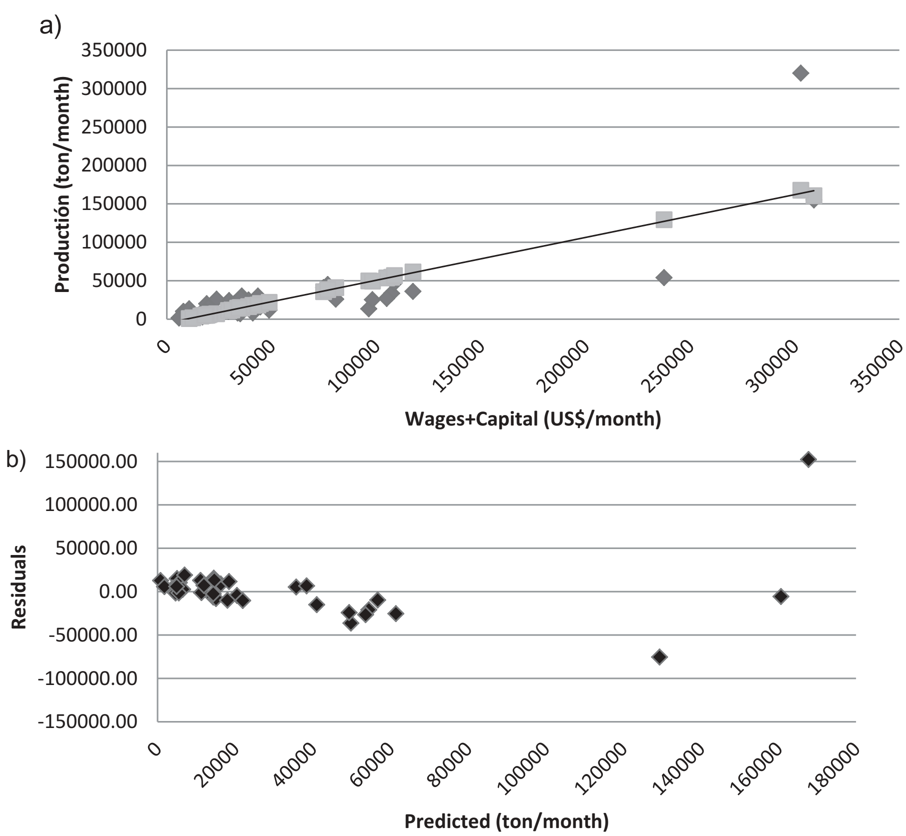

Figure 1. Quadratic production function model for monthly production for the three countries, based on combinations of capital and wages (a); and distribution of predicted versus residuals (b).

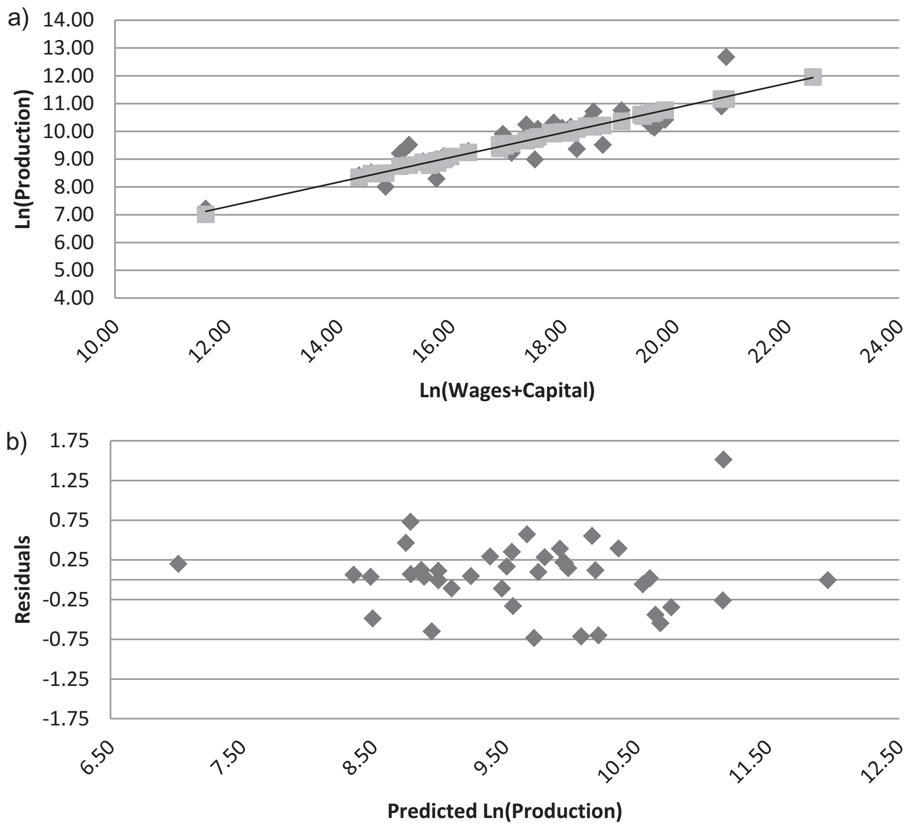

Figure 2. Cobb-Douglas production function model for monthly production for the three countries, based on combinations of capital and wages (a); and distribution of predicted versus residuals (b).

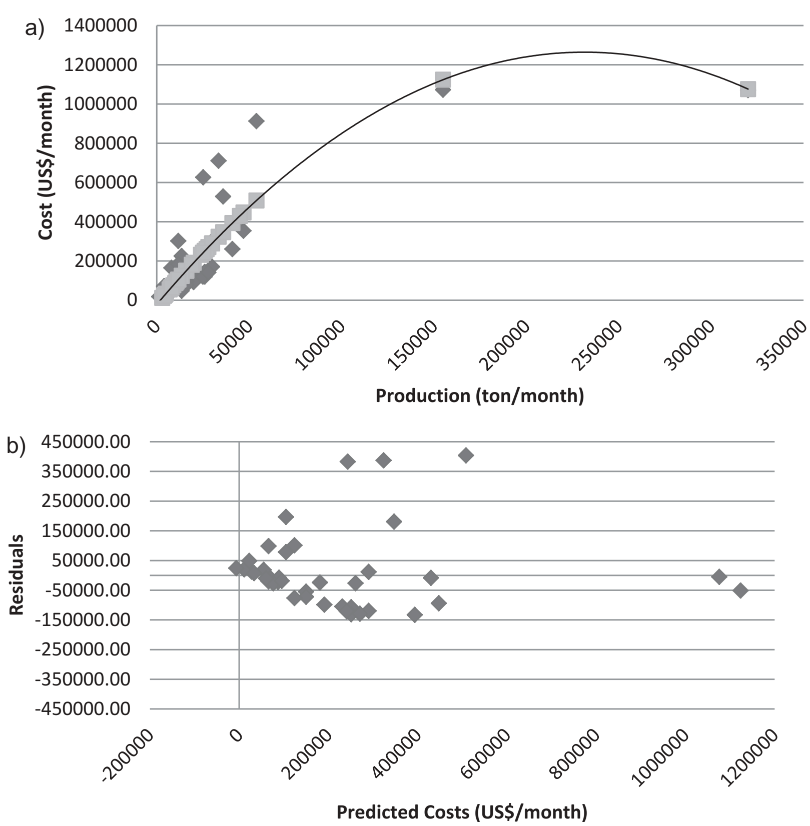

Figure 3. Total cost model for the three countries based on the quadratic model (a); and distribution of predicted versus residuals (b).

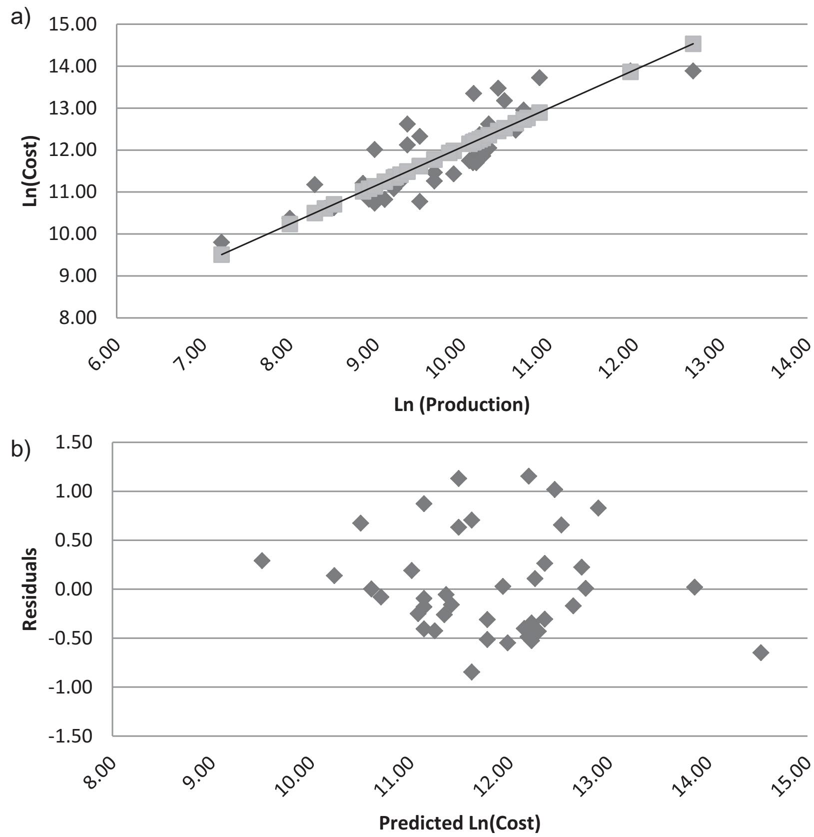

Figure 4. Total cost model for the three countries based on the Cobb-Douglas function (a); and distribution of predicted versus residuals (b).

production, any logging contractor who wanted to increase production from 5000 to 10,000 tons per month would have doubled its total monthly cost. Thus these are the most difficult stages of growth for logging companies, especially if it is difficult to access capital. Again, the Cobb-Douglas models showed more uniform residuals distribution, and also the Furnival Index was better (8292) versus the quadratic model (25586) (Figure 3).

While acceptable and statistically significant, the costs per ton in the quadratic models did not have as good regression results as the log functions described above, but provided mostly consistent findings (Figures 5 and 6). The contribution of mechanization was positive and clearcutting negative. This would suggest that with semi-mechanized companies there would be an increased cost, although it decreased if they perform clearcutting. This analysis also confirmed that the variables that affect the cost per ton model most were mechanization and Uruguay. This suggests that would be more appropriate to make cost comparisons of individual quadratic models by country.

Discussion

A total of 67 logging firms in Brazil, Argentina, and Uruguay working in forest plantations were interviewed personally to examine their production and cost characteristics. This is a robust sample, across several countries, which provides a basis for sound inferences about logging costs. Of the firms interviewed, 41 were fully mechanized and 26 were semi-mechanized. Some harvested only one species, and others two; 36 harvested pines, and 38 Eucalyptus. Similarly, some logging firms only operated in clearcuts, and others specialized in thinning, and some had both operations.

According to our estimates, we surveyed 45% of the number of logging contractors in Argentina, 16% in Brazil and 38% in Uruguay. When considered as a share of total production in the region, we sampled a weighted average of 21% of the firms, with an annual production of 17.7 million cubic meters.

The macroeconomic factors indicated that fairly similar conditions existed between Argentina and Brazil. Uruguay was characterized by lower interest rates, higher wages, and higher fuel price. As for contracting companies, pulp companies in the three countries hired the most contract services, while saw mills were only somewhat important in Argentina and Uruguay.

The total production costs and the contract logging prices paid were significantly higher in Uruguay than in Argentina and Brazil. When the costs were analyzed, it was observed that logging contractors working for pulp companies have significantly higher capital value and the largest payroll. Similarly, the fully mechanized logging firms had the highest capital level. Taxes were significantly lower in Argentina. Despite statistically significant differences in some factor prices and in logging costs, there were not statistically significant differences in the profit margins either by country or by type of operations. This might be attributed somewhat to the still relatively small sample of firms per country, and the

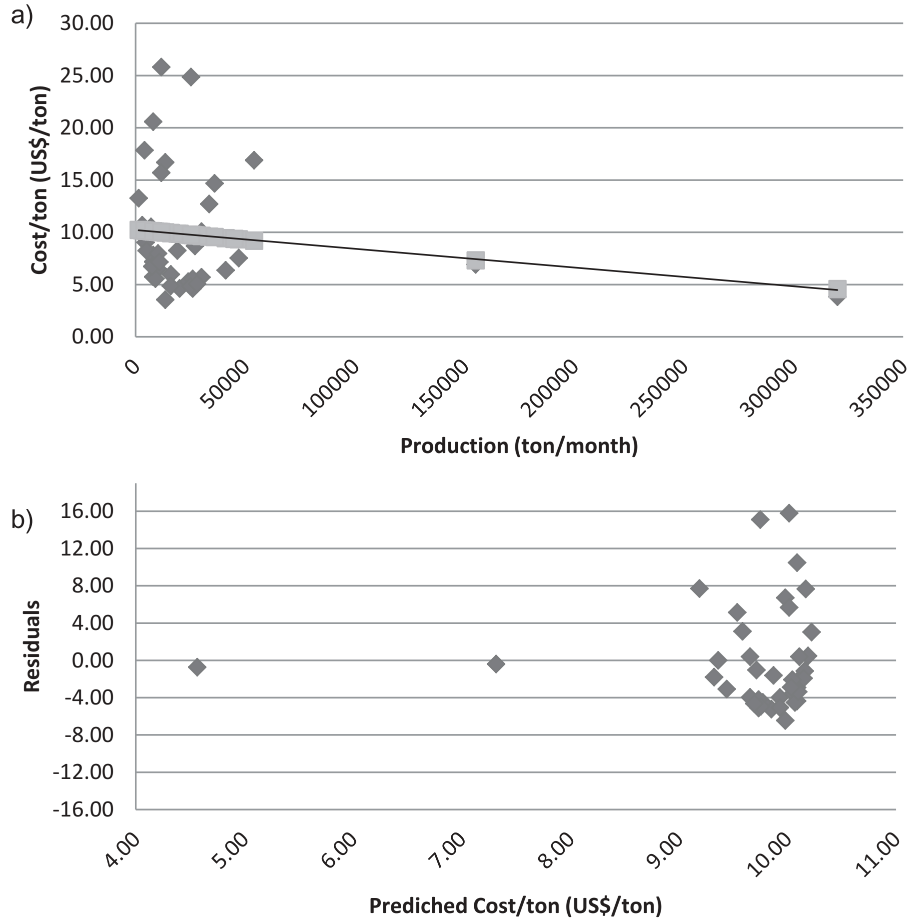

Figure 5. Average cost per ton model for the three countries based on the quadratic model (a); and distribution of predicted versus residuals (b).

considerable variability in the average profits per firm – with standard errors sometimes as large as the mean.

For the production function regression models, wages and the "dummy" Uruguay were two of the most significant factors. This model showed better statistical results (r^2 = 0.75) than other literature. These excellent results could be largely attributed to collecting primary data by one highly trained interviewer, rather than relying on broad secondary cross-sectional data. The logarithmic Cobb-Douglas production models produced better indicators than quadratic regression models, and the elasticity of the capital was higher than that for wages.

The prices paid for thinning were higher than those for clearcutting, but without much differences in production costs between the two operations. This might suggest that there is no need to pay loggers more for thinning, but it is still difficult to accept that a partial harvest average costs are no greater than those for a clearcut, so bears more investigation.

The Cobb-Douglas models were statistically better than quadratic models either for total cost, or in the cost per ton. Based in both residuals distributions, and the Furnival Index, they also were superior. This coincides with the findings of Carter and Cubbage (1994), Bauch et al. (2007), Cass et al. (2009) and Stuart et al. (2010). The Cobb-Douglas models showed that there was a very high need for capital to start of production, but there is a major change since the 50,000 tons/month, while the cost curve is asymptotic at 100,000 tons/month.

Also, we found that the size of the logging firms in these three countries could be larger than those reported for south-eastern USA (Siry et al. 2006; Baker & Greene 2008; Stuart et al. 2010) and for Scandinavia (Hultaker and Bohlin 2004; Eriksson & Lindroos 2014). However, average logging costs were not as low as reported in those countries.

The average cost calculations appear to be reasonable. The studies mentioned above have harvesting costs similar to those obtained in this research, between US$10 and US$15 per ton. Timber Mart-South (2013) of the United States publishes average harvesting prices and a cost index of harvest pine forests in the Southern USA. These values have a range between $ 11 to $ 13 US$ per ton between 2008 and 2013, which are similar to the costs calculated in this work.

In conclusion, we found greater production elasticity than reported in prior U.S studies (Carter et al. 1994; Siry et al. 2003). The inflection point to realize most of the returns to scale appears at a production level higher than reported in the literature and was related to the large size of logging firms in each country. Again, the detailed data collection methods probably led to better model estimation as well. This could be attributed to our more detailed personal survey interviews

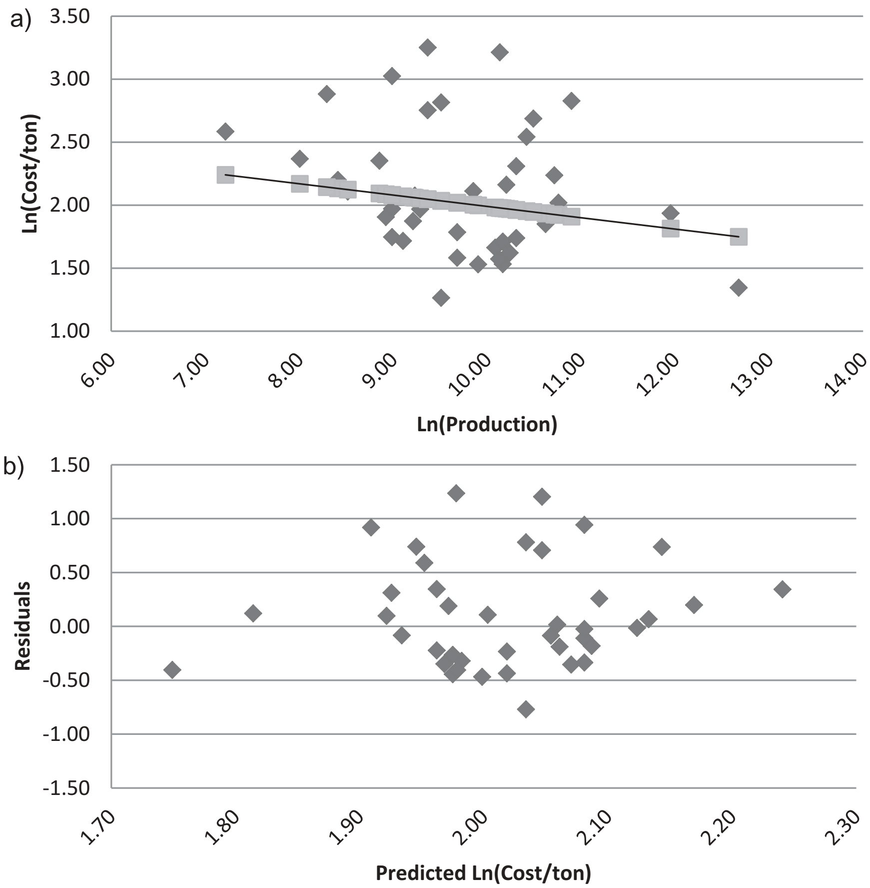

Figure 6. Average cost per ton model for the three countries based on the Cobb-Douglas model (a); and distribution of predicted versus residuals (b).

compared to prior literature which is based on regular mail, secondary sources, email, or Internet surveys which perhaps received less attention from companies. Our methods were corroborated carefully to ensure that there was no bias in the data, so the regression results and differences in significance of the factors of production reported here seem reasonable.

These findings, while robust, are apt to change under different macroeconomic conditions, technology, and logging experience over time. Argentina and Brazil at least have had marked changes in their political administrations and macroeconomic conditions, which are apt to adversely affect performance of all businesses in those countries. Uruguay has had more stable politics and macroeconomics, which would help all companies in the country. Uruguayan loggers had five or more years of experience and relatively less expensive equipment which should allow them to be more competitive. The constant changes in timber harvesting productivity, costs, and contract prices will always make the logging sectors dynamic, but our broad cross-country research provides a sound benchmark for this portion of South America.

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Authors' contributions

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