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Chapter

Timber Harvesting Production, Costs, Innovation, and Capacity in the Southern Cone and the U.S. South

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Abstract

We performed research in the Southern Cone of South America and in North Carolina USA that examined logging production, costs, innovation, and capacity. We compare the findings of this timber harvesting research up until 2015 between South America and the U.S. South, and draw conclusions regarding comparative forestry sector economic advantages. Logging production rates per firm have increased, reaching as much as 200,000 tons per year in the U.S. South, and more than 300,000 tons per year in the Southern Cone. Average total costs for logging were generally less in the Southern Cone, at less than $10 per ton for cut and load at roadside for transport, and more than $12.50 per ton for cut and load in the U.S. South. Logging firm innovation usually led to greater production and reduced costs, and focused mostly on improved timber harvesting systems and processes and use of firm performance monitoring, software, and training. Logging sector capacity was a concern in the U.S. South given aging owners and workers, and most likely to come from expansion by existing firms. The Southern Cone had better prospects to expand logging operations due to higher production rates and more favorable rural worker attitudes toward logging employment. Overall, logging production rates will increase; average total costs are apt to remain relatively stable; innovation will focus on system improvements and management skills such as measurement and monitoring; but capacity for sufficient in the woods and transport workforce will be a continuing issue.

Keywords: forest harvesting, logging, productivity, capacity, innovation, Southern Cone, USA South

1. Introduction

Global competition for wood supply is intense, and it is expected to increase more in the future in order to meet the growing demand for wood fiber [1]. Increased demand places continued pressure on the world forests, and more effective utilization of forests is one of the best and most immediate responses to contribute to forest conservation. The timber and forest products industry value chain begins with standing timber in forests and extends to a variety of manufactured forest products. Contract and independent timber harvesting and transport firms comprise the key link in the supply chain to move timber products from the woods to the mill.

Timber harvesting efficiency and utilization improvements are reflected in reduced costs, and comprise a large share of delivered wood and mill costs for forest products firms. For example, a survey by Hahn [2] in North Carolina found that logging costs averaged 35% of the total wood costs delivered to a mill, with trucking adding another 18%, stumpage 39%, and wood dealer/procurement costs 8%. This chapter focuses on analyses of the comparisons of logging productivity and cost component of the overall timber production, harvesting, and transport value chain in the Southern Cone of South America and the U.S. South.

The different labor, harvesting and transportation systems' costs, coupled with the fluctuation of exchange rates, have led to different levels of supply costs in different countries over time [3]. These harvesting operation components complement differential yields from fast growing forest plantations, which favor South America. These integrated timber growth and harvesting supply chains make it possible to more effectively satisfy demand, reduce the rising real cost of wood, and conserve global forests [4].

The timber and forest products industry value chain begins with standing timber in forests and extends to a variety of manufactured forest products. Private logging firms are key links in this supply chain and may range from independent contractors who buy and harvest timber without long term contracts, to companies with long term contracts with forest products manufacturing facilities, to company crews that work for small or medium size sawmils. Timber logging firms have often been characterized as having high capital requirements, with modest profits per unit of wood harvested. This necessitates both efficiency and high volumes of output to offset high equipment fixed costs. In the Southern Cone of South America, logging firms have expanded from small scale local operations to more sophisticated capital-intensive operations as the forest industry has expanded greatly in the last few decades. In the U.S. South, mechanization occurred sooner, and continues apace, but scarce labor and capital availability have created concerns about the viability of the logging force throughout the Americas.

1.1 Objectives

The objective of this chapter is to summarize findings from recent research that we have completed and other relevant literature on timber harvesting (e.g., logging) production and costs in the Southern Cone of South America and in the U.S. South, in order to examine the contribution of logging to overall forestry sector comparative advantage between the two regions. We cover our empirical research on timber harvesting in the Southern Cone and in North Carolina in the U.S. South, and buttress this with extensive literature on logging throughout both broad regions.

The Southern Cone comprises the countries of Brazil, Uruguay, Argentina, and Chile; the U.S. Southern forests consist of 13 states running from Texas in the west to Virginia in the East. These two regions combined produce more than 20% of total global roundwood production as of 2008, with about 180 million m^3 of wood produced in 2008 in each region compared to the global total of 1.5 billion m^3 [5]. The Southern Cone industrial roundwood production increased about 25% since then [6], while the U.S. South remained fairly constant [7].

Global forest industry profits were decreased by the U.S. housing crisis and the general economic recession of 2007, and the pressure on profits and long run logging contractor supply has been problematic. Manufacturing capacity in the U.S. and in the Southern Cone has since rebounded, but concerns remain that a reduced logging force could hinder forest industry expansion in the Americas.

In order to assess future prospects for timber harvesting capacity and innovation in the Americas, we will examine logging productivity, costs, capacity, and innovation in the Southern Cone and the U.S. South using mixed methods of theory and principles, case studies, and literature synthesis. This will include a broad overview of logging firm productivity and costs in the Americas; a detailed analysis of production and innovation in the Southern Cone; and a simulation of the amount of capacity needed to meet projected increases in wood fiber production the state of North Carolina, USA. Conclusions regarding logging productivity, capacity, innovation, and prospects will be drawn from this synthesis.

1.2 The wood supply chain

The U.S. wood supply chain has undergone significant changes over the past 30 years. Intensive forest management increased forest productivity dramatically. Logging businesses, logging business owners, and their equipment have changed as well. Logging businesses rapidly mechanized their operations during the 1960s–1980s, and the logging industry transformed from a labor-intensive to a capital-intensive industry [8].

South America has substantially expanded its forest plantations and raw material supply. From 1997 to 2005, South America had a high annual growth rate in the production of industrial roundwood, with Brazil and Chile being the most important countries [9]. South America also has the fastest growing industrial timber plantations in the world, comprised mostly of exotic softwood species from the United States and eucalyptus from Australia [10].

From 1997 to 2005, Asia had the only negative regional production growth rate in the world, and China became the largest roundwood importer in the world [9]. The forest industry has grown consistently in recent years, and much of this growth have been focused in the Southern Cone countries of Brazil, Chile, Argentina, and Uruguay. Like any global commodity industry, forest production and harvesting are driven by costs. The development and competitiveness of companies have been based on planted forest and timber harvesting factors like low production costs, excellent plantation growth, and the availability of large areas for afforestation [10, 11].

Independent timber harvesting companies are the vital component of the wood supply chain that harvest timber on public and private forestland and deliver it to forest products mills. Without logging businesses, gains in forest productivity cannot be captured and the chief advantage of forestland investments, biological growth, could not be monetized well [8].

1.3 Timber harvesting production, costs, and innovation

Timber harvesting average total costs depend on the productivity and cost of the individual factors of production such as feller-bunchers or harvesters, skidders or forwarders, loaders or chippers, trucks, and labor. In addition, management skill, entrepreneurship, innovation, safety, infrastructure of roads and government, and environmental protection measures affect average total harvesting costs. Various principles and literature address these factors that affect timber harvesting productivity and capacity.

For the most part, independent logging contractors perform most of the logging now in the Southern U.S. and in the Southern Cone. In 1960s–1970s in the Southern U.S., many large integrated forest products firms had their own logging crews, but they were consistently more expensive than similar independent crews, due to less productivity and higher average wages than independent crews, and the need to pay higher costs for some social insurance than small operators. Thus all major U.S. pulp and paper firms phased out of the logging business by the 1980s. Some separate wood dealers still do maintain contract logging crews, as do some small sawmills. This trend to independent loggers for large forest products firms also occurred in the Southern Cone.

The independent logging capacity has increased through the last 25 years, mainly based in more and bigger equipment. For example, 20 years ago, a common skidder had a 5 tons payload, and nowadays has increased to more than 10 tons. In the case of forwarders 20 years ago a 10 tons loading capacity was common, and nowadays goes up to 20 tons. In the same way, capital invested in machinery increased; 20 years ago, a standard equipment mix demanded about US$ 500,000, and today needs more than US$ 1.5 million [8, 11].

As firms have increased their capital investment, average production per dollar invested has declined. Annual production per $1000 invested declined from 200 tons in 1987 to 140 tons in 2012 [8]. Loggers must remain profitable to remain in business and continue investing in their businesses. Therefore, the logging and forest products industries must innovate in order to remain competitive globally.

Technology innovation in forestry has been described as following paradigm shifts and discontinuous evolution. Technology innovations in general are also referred to as technology change, technology shift, and technology development. The *Oslo Manual* [12] provides one of the most comprehensive definitions of innovation because it allows for consideration of new products, processes, markets, and organizational methods with respect to an individual firm. Then because of an innovation a novel device or method is offered to the market (technology push) or market needs trigger innovations (market pull). Drivers for the innovation process can be either internal or external.

Lindroos et al. [13] describe three main drivers of harvesting mechanization: new technology, new products, and new rules. They argue that irrespective of the size of jumps in technological advances, those expected over the next few decades will most likely be seen as fine tuning of current timber harvesting operations. Stone et al. [14] surveyed 13 logging contractors in Maine (USA) to assess innovation. Based on the Oslo manual, they characterize innovation in four types: (1) Product, (2) Process, (3) Organizational, and (4) Marketing. Product innovation consists of introducing a significantly improved good or service. Process innovation focuses on a significantly improved production system. Organizational consists of a new method in the firm's business practices, workplace organization or external relations. Marketing involves significant changes in product design, placement, promotion, or other strategies. In Maine, they found that logging innovators can and will engage in four types of innovation, but process and product innovation dominate [14].

Externally driven process innovations were most common according to the Maine study, such as new equipment or system configurations, machine computer or GPS applications, or new high flotation tires and tracks for equipment. These generally focused on increasing profitability through reduced cost per unit of production. Product innovations, such as road maintenance, power line maintenance, or specialty harvests, were more common than new products, such as biomass or firewood. Organizational innovation was less common, but controlled more by innovations within the firm. This included better information gathering and analysis by the firm, including computer programs, customized tracking systems, and targeted efficiency improvements. Innovations in marketing their services were used the least by firms, and then mostly in areas with multiple small tracts. However, four firms did note that they had logging certification with one of the two major systems, which did help them get access to markets that noncertified loggers could not [14].

Drawing from OECD and Eurostat [12], Stone et al. [14] provide a useful schematic of the logging innovation system in Maine or elsewhere (**Figure 1**).

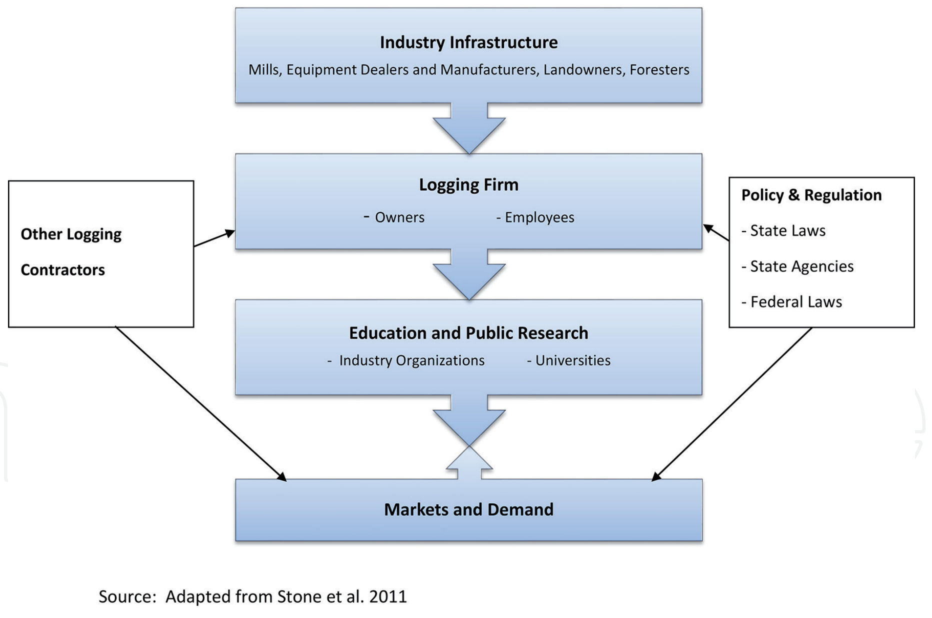

Figure 1.
Logging innovation system in Maine [14].

The external industry infrastructure—mills, equipment manufacturers and dealers, landowners, and foresters—has the most direct influence on logging innovation. Internal drivers are of course the owners and employees of the firm. Firms are also influenced by other logging contractors, and business and environmental policy and regulation, including state and federal laws and state agencies. Education and public research were posited to affect innovation, but not examined in the Maine case studies. Finally, markets and demand provided feedbacks to firms, instigating innovation.

2. The Southern Cone

We analyzed timber harvesting production, costs, and innovation in the Southern Cone of South America based on an extensive survey conducted by the senior author of this chapter, which provided details for the region. In the Southern Cone, forest harvesting activities are carried out through logging contractors that have emerged through the phenomenon known as outsourcing. This is the most common approach for a company that owns forest plantations. Many contractors have been attracted to the logging industry in the Southern Cone, but have failed, because they are not able to maintain both the requirements of the contracting company, and their own company's profitability. It can be inferred that much of the successful contractors could be in practice employees under contract to the larger companies, or in other cases, leading entrepreneurs, who have been able to innovate in the business, and thus develop agile and flexible companies that make a successful long-term business relationship [15].

To meet the increases in demand, to lower logging costs, to reduce environmental damage, or to achieve or maintain levels of global competition, the introduction of technology was one key driver in expansion of the forest products sector in the Southern Cone. For much of the 1980s and the 1990s, the introduction of technology occurred through machinery investment, and from about 1990, technology has included investment in hard technologies (equipment) and soft ones (training, computer programs). Increasingly more companies incorporate soft technologies in timber harvesting, which will increase in the future. However, the largest total investment amount still is for machinery.

2.1 Firm production and cost models

Mac Donagh et al. [11] surveyed 67 logging companies in Argentina, Brazil, and Uruguay, which comprised a substantial 20% of the total timber harvest production in the three countries. They estimated logging production and cost averages and functions for each of those countries in the Southern Cone. **Table 1** summarizes the average production per month and total average costs per ton for the Southern Cone by country, species, contractor type, and mechanization level. Argentina had the lowest average total logging costs (US$ 7.41 per ton), but they were not significantly different than Brazil (US$ 8.41 per ton). Costs in Uruguay were significantly greater at $14.81 per ton. Brazil and Uruguay had the highest average production levels, albeit not significantly greater than Argentina due to the considerable variability in the sample.

Another notable finding of the extensive Southern Cone research was that average total costs did not vary significantly among pine, eucalyptus, or mixed species harvests, nor did production per month. Logging firms that had contracts with pulp mills averaged three times as much production per month, but had about the same costs as those who logged for sawmills. Production levels for fully mechanized firms were more than five times greater per month than for semi-mechanized firms. Average production levels were greatest for mixed harvest types; second for final harvests; and least for thinnings. However, average total costs were not much different, and in fact cheapest for thinnings, but none of these averages were statistically different.

Variable/mean	n	Average total costs (US$/ton)		Average production (ton/month)	
		Cost	Standard error	Production	Standard error
Region					
Argentina	22	7.41	0.89	13,616	9167
Brazil	17	8.19	0.71	26,291	7268
Uruguay	10	**14.82**	1.32	25,660	13,597
Species					
Pine	28	8.35	0.92	16,827	14,317
Eucalyptus	30	9.31	0.89	22,643	8117
Both	9	9.44	1.63	36,211	7842
Contractor type					
Sawmills	29	8.63	0.90	9402	7725
Cellulose	38	9.15	0.79	**31,676**	6748
Harvest type					
Thinning	14	8.43	0.74	11,607	6520
Final harvest	43	9.53	1.30	22,045	11,427
Both	10	10.22	1.53	36,590	13,521
Mechanization level					
Semi-mechanized	20	8.82	0.71	5423	9314
Fully mechanized	47	9.18	1.09	**29,104**	6076

Numbers in bold signify statistically significant differences per Tukey HSD at p = 0.05.

Table 1.
Selected results of an analysis of variance of logging firms in the southern cone, 2011–2012 survey data.

DOI: http://dx.doi.org/10.5772/intechopen.85412

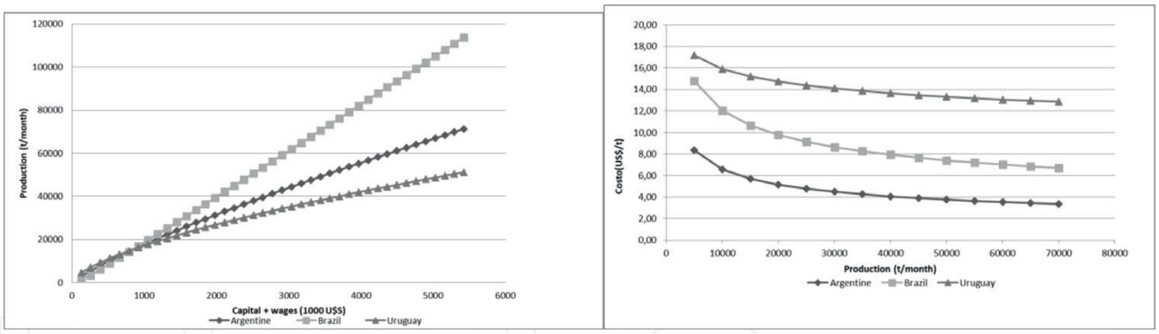

Figure 2.
Logarithm production and cost by ton models for Argentina, Brazil, and Uruguay.

The logarithmic production and cost functions by country from Mac Donagh et al. [11] are shown in **Figure 2**. Production per month increased with varying returns to scale as a function of capital and wages, and average total costs as a function of production per month were asymptotic L-shaped curves that roughly bisected the average costs listed in **Table 1**. The average total cost for Argentina had a minimum value at 18,000 tons per month with a cost of US$ 5.82 per ton. The Brazilian logging companies had higher production levels, at a somewhat higher level than Argentina. The lowest cost was of US$ 11.23 per ton, at a production of 25,000 tons per month. If production doubled, (50.000 tons per month) the cost decreased by 14%.

The results showed that that Brazilian loggers had the largest price elasticity to production changes, followed by Argentinean and Uruguayan logging firms. The elasticity of capital was 0.59 for Argentine loggers, 0.55 for Uruguay, and 0.4 in Brazil. For wages, the elasticity was 0.09 for Uruguay, 0.22 for Argentine and 0.63 for Brazilian loggers. Thus Brazil logging companies had the largest total factor elasticity (1.03), Argentina the second (0.81), and Uruguay the third (0.64). This indicates that at the mean values per country, additional capital would be most effective in Argentina (which has the least capital investment to date), and additional wages most effective in Brazil (which has the most capital).

2.2 Equipment technology and systems

Harvesting technologies have varied a lot in the period under consideration. While in the SE of the United States the most common mechanized systems are with feller-buncher and skidder, in the Southern Cone, there are different situations (**Table 2**). Feller-bunchers dominate in Argentina while they are very rare in Uruguay. Rubber tired harvesters are more frequent in Uruguay, while they are very rare in Brazil. In Uruguay, the harvester/forwarder system that is common in Scandinavia has been widely adopted, basically for eucalyptus clear cuttings. In Argentina, for clear pine felling, the most common is a system uses a feller-buncher, both crawled and wheel; rubber-tired skidders, and then processors at roadside. In pine thinning, although there are still operations with chainsaws, the most frequent are both small wheel harvesters, as well as small processors.

On the other hand, if we analyze the size of the companies, or the dispersion among small, medium and large companies, the Southern Cone had companies that produced from 5000 tons per month up to more than 100,000 tons per month. As noted, this generated average total logging costs per ton that varied from US$ 3.27 to US$ 25.81 per ton, with an average value of US$ 7.14 per ton for Argentina, US$ 8.41 per ton for Brazil, and US$ 14.16 per ton for Uruguay.

	Argentina (%)	Brazil (%)	Uruguay (%)	Total
Felling				
Harvesters	35	5	60	40
Fellers	48	39	13	23
Processors	20	57	23	91
Logging				
Forwarders	17	25	58	48
Skidders	47	45	8	38
Farm tractors	51	20	30	81
Loading	36	56	8	77
Source: Mac Donagh et al. [11].				

Table 2.
Forest operations mechanization in Argentina, Brazil and Uruguay.

2.3 U.S. South production and cost comparisons

In the early literature for the Southeast U.S, smaller companies had computed average costs in the order of US $20 per ton [16], with companies that produced from 184 tons per month to 2600 tons per month for different harvesting system technology classes. More recently, Baker and Greene [17] report an increase in the size of logging contractors between 1987 and 2007 in Georgia. Companies with feller-skidder technology had reached an average production of 5828 tons per month per crew, or about 70,000 tons per year [18–21], with an investment of US$ 473,800 per crew [17].

In a more recent 2015 logger survey in North Carolina Coastal Plain, Hahn [2] found that loggers in eastern North Carolina produced 2960 tons of roundwood per firm per week, and worked 49 weeks per year. Thus the current North Carolina logging firm average production was 148,000 tons per year, although this did consist of some firms with multiple crews. Baker et al. [22] interviewed 22 logging firms across the South and reported average weekly production among those firms to be 4197 tons, which would be about 200,000 tons per year.

These average U.S. South production rates were usually on a per crew basis, but still were considerably less than the average rates of about 300,000 tons per year per firm in Brazil and Uruguay in 2012, which included some firms with multiple crews, and almost all of whom were harvesting quite uniform planted eucalyptus or U.S. Southern pine, mostly loblolly (*P. taeda*). Some of the higher reported individual firm average production rates in the Southern Cone were more than 400,000 tons per year. This might reflect the fact that loggers had multiple machines per crew—e.g., two feller-bunchers and several skidders—while the U.S system commonly only had one feller and two skidders. Several firms also ran multiple shifts per day, increasing production rates.

In addition, final harvest volumes in the Southern Cone were often almost twice as high, because the rapid growth per year and stocking per unit of area was that much greater than in the U.S. South [10]. With slightly shorter 18–22 year rotations, loblolly pine stands in the Southern Cone would produce and harvest more than 500 tons per hectare (200 tons per acre) at age 18–22, versus 250 tons per ha (100 tons per acre) in the U.S. South at age 25. This allowed much greater logging production from dense, closely spaced planted stands. Eucalyptus stand volumes were more like the 250 tons per ha (at ages 6–12), but the stands were almost all very similar clones in uniform stands, usually planted on relatively accessible lands, again facilitating timber harvesting.

Timber Mart-South [23, 24] showed a trend of increasing harvesting costs in the US Southeast. This variation goes from US $ 11 per ton 2009, to US $ 12.92 per ton for 2013. Baker et al. [25] estimated a logging cost index for the South, and set the initial cut and load at roadside logging value in 2011 as US$ 12.50 per ton. These values are somewhat greater than those that we calculated for Argentina and Brazil in the Southern Cone for the same period, but not Uruguay. Siry et al. [3], in a benchmarking comparison between different countries, found that logging costs for pulpwood was about US$ 11–13 per ton in the U.S. South, and US$ 5–7 per ton for Brazil. According Siry et al., low costs in Brazil were based on cutting-edge machinery, use of two to three shifts, and operators with a high training level.

3. North Carolina logging production and capacity

The timber harvesting literature reviewed above compares timber harvesting production and costs in the U.S. South with those of the Southern Cone at the beginning of the 2010s. From 2014 to 2016, we conducted research in North Carolina on timber harvesting production, costs, and capacity that provides an excellent benchmark for comparison to the prior Southern Cone research and earlier Southern U.S. literature. That research examined the status of logging and wood procurement in North Carolina, and whether we would have adequate harvesting capacity as timber production as mills increased their production after the recession of 2007. That research is summarized here, drawing from master's degree research by Hahn [2] and Roll [26] in cooperation with Cubbage.

Hahn [2] surveyed 27 procurement and logging firms in North Carolina, including questions about production, costs, and business environment. Roll [26] built on the results found by Hahn and focused on the question of a sufficient logging workforce, and derived estimates of logging production rates using a simulation approach based on "Arena" software, developed by Rockwell Automation [27]. In concert then, our research team developed a model of the timber supply chain path from the stump to the processing mills to estimate production levels of and requirements for harvesting crews in the Coastal Plains of North Carolina. These integrated efforts provide further insights into timber harvesting innovation, management, and capacity.

3.1 Logging capacity measurement

Adequate capacity for harvesting timber has been a continual issue for decades in the forestry sector. We analyzed timber harvesting and logging capacity in North Carolina's Coastal Plain region given structural economic trends and conditions after the recent 2007 recession and consequent downturn in the forest products industry [28]. Forest products industry profits have been squeezed by the housing and general economic recession, which has been forced down the supply chain to logging firms. Manufacturing capacity at pulp mills and sawmills has begun to return to pre-recession levels, but concerns remain that a reduced logging force could hinder the sustainability of manufacturing facilities. For reference, Baker et al. [25] report the median share of input costs for timber cut and haul average costs in 2011, with labor costs being the largest at 33% of the total. These are followed by fuel and oil (23%); equipment depreciation and interest (20%), repair and maintenance (11%), insurance (5%), and administration (4%).

Greene et al. [19–21] conclude that labor issues in the logging sector are a concern with an aging labor force and highly qualified workers seeking other employment, and note that the age of logging firm owners in the U.S. South has increased nearly 10 years over the past two decades. Not only is the workforce aging or altogether leaving, a similar survey reports that recruiting workers is also a significant concern to business success by firm owners [29]. A technical release from Wood Supply Research Institute [30] states that "new entrants into the wood supply business will be spotty at best," leading to the conclusion that any expansion in capacity with mostly be supported by existing wood suppliers. These discouraging trends in the U.S. might exacerbate any competitive disadvantages that were already evident as summarized in previous research.

Traditionally, the metric of "logging capacity" is expressed as how much a harvesting crew actually produces as a proportion of how much a crew could produce, during a given time period. While expressing logging capacity this way is certainly useful, it may not be the most pragmatic metric when assessing if the logging industry is capable of supplying adequate levels of wood fiber. Because most crews run at near-full mechanization, expansion of timber output is likely to depend most on scarce additional skilled labor to operate the increasingly sophisticated harvesting machinery. Thus our North Carolina study analyzed logging capacity in terms of additional labor required to meet wood demand.

3.2 North Carolina research methods

Face to face interviews were conducted between May and August 2014 with 27 subjects. Potential subjects' contact information was obtained from the North Carolina Forest Service website which contained a list of timber buyers, wood dealers, loggers, and mills in North Carolina. Subjects were contacted by telephone and notified of the scope and purpose of the interview. Of the 27 subjects, 13 were procurement foresters, six were wood dealers and eight were loggers. The subjects represented 23 different counties, with 21 in North Carolina, one in Virginia and one in South Carolina. Data from the surveys were summarized, and divided into regions—the western part of North Carolina with more relief and Mountains and hardwood species production; and the eastern part of the state, including the Piedmont and the Coastal Plain, and more pine timber production.

Subsequently, using the Arena Simulation software, we constructed a simulation model to approximate annual softwood and hardwood harvest levels for an individual logging crew. Next, we converted the most recent Timber Product Output (TPO) data in 2011 from cubic feet to tons using Timber Mart-South's weight equivalents to better understand historical harvest levels in our target market. Afterwards, employment in the logging industry (NAICS 113310) was retrieved from the Bureau of Labor Service (BLS) for Coastal Plain counties. Because the BLS reports employment as all employees paid by a logging firm, we consulted a previous logging survey in the coastal plain of Virginia to get an estimate of average "in-woods" crew sizes [31]. With this information we were able to estimate the number of logging crews required to produce 2011 levels of timber output as well as increased wood demand in subsequent years as forecasted by the Southern Forest Futures Project [32].

The simulation model designed in this study was subdivided into four interrelated segments in order to group activities that occur in the same harvesting activity (felling, skidding, sorting, loading). Each segment was simulated separately, and then linked into one integrated harvest simulation model using the Arena software package.

3.3 North Carolina results

3.3.1 Logging and procurement survey

Several results from the survey of procurement and logging firms [2] bear on the questions of timber harvesting production and capacity and comparisons with prior U.S. literature, as well as with the Southern Cone. The 13 procurement foresters and 6 wood dealer interviews indicated that for wood costs delivered to a mill, stumpage was the largest cost at 39%, logging costs were second at 35%, followed by hauling and wood dealer fees at 18% and 8% respectively (**Table 3**).

The eight logging firms interviewed had a mix of one single crew to several crews. In terms of operations, the average number of employees for each subject was 16, with a minimum of 2 and maximum of 30. Employee wages averaged at $13.75/hour, with the minimum being $11.00/hour and maximum of $15.50/hour. The average equipment spread was three feller-bunchers, three skidders, three loaders, one bulldozer, two chippers, seven chip vans, four trucks, five log trailers, and two processors.

The average length of time logging was 36 years with a minimum of 10 years and a maximum of 60 years. Average years that subjects had owned their business was 33 years with a minimum of 10 years and maximum of 60 years. Average weeks worked per year was 50 with a minimum of 47 and maximum of 52. Average hours worked per week was 51 with a minimum of 40 hours and maximum of 75 hours per week (**Table 4**). When asked to describe the type of operation, 62% subjects described their operation as an independent logging company. The remaining 37% were classified as contract loggers for wood dealers.

Average weekly production per firm was 1554 tons in pine and 1279 tons in hardwood (about 6200 and 5100 tons per month, or 76,000 and 63,000 tons per year respectively). For softwood product mix, the average breakdown was 47% pine pulpwood followed by 32% pine sawtimber, 12% pine chip-n-saw, and 9% pine biomass. For hardwood products, pulpwood was the most common product harvested at 44%, followed by sawtimber (32%), biomass (19%), and chip-n-saw (5%) respectively.

Category	North Carolina (%)	Western NC (%)	Eastern NC (%)
Stumpage	39	40	39
Logging	35	41	30
Hauling	18	19	16
Wood Dealer	8	0	15

Table 3.
Breakdown of average total delivered wood costs by category in North Carolina, 2014.

Business characteristic	Average	Minimum	Max
Years spent logging (years)	36	10	60
Years owned own business (years)	33	10	60
Weeks worked/year	50	47	52
Hours worked/week	51	40	75
Number of employees	16	2	30
Employee wage ($/hour)	$13.75	$11.00	$15.50

Table 4.
Business characteristics of loggers surveyed in North Carolina.

Logging rate or characteristic	North Carolina mean	North Carolina std. dev.	Western NC mean	Western NC std. dev.	Eastern NC mean	Eastern NC std. dev.
Cut and haul ($/ton)	13.74	1.65	15	2.85	13.33	1.18
Haul to mill ($/ton)	4.22	0.92	3.5	0.21	4.46	0.95
Haul distance (miles)	47	11	38	4	50	11

Table 5.
Logging payment rates in North Carolina, 2014.

Eastern logging crews were larger with an average of 18 employees, while western logging crews had an average of three employees. While there was no significant difference in the length of time each subject had been logging, there was a difference in the percentage that bought stumpage. In the western part of the state 100% of the subjects bought stumpage compared to 67% of subjects in the eastern region of the state. Likewise, 100% of western loggers were independent operations compared to 50% of eastern loggers.

The average timber harvesting cut and load rates were $13.74/ton and ranged from $12.00 to $17.00/ton. The average haul rate was $4.22/ton with a minimum of $3.35 and $5.50/ton. The average haul distance one way was 47 miles and ranged from 35 to 60 miles (**Table 5**).

3.3.2 Logging capacity simulation

The logging capacity simulation using the Arena software estimated the baseline scenario of the amount of timber harvesting production per crew in Eastern North Carolina as a case study, and then estimated how much added logging capacity would be required if additional product demand were increased from the low point in 2008 during the recession [26]. The Arena simulation estimated a logging operation of one feller-buncher, two skidders, and one loader as the typical harvesting spread based on the interviews from Hahn and other literature. Productivity rates by machine also were obtained from prior literature. These machine productivity rates were then entered into the simulation to model total harvesting system productivity per ton. The simulation results also were checked for validation with a spreadsheet with a generic harvesting tract based on the Auburn Harvesting Analyzer [33].

On average, each ton of wood spent 1.81 hours (108.6 minutes) in the entire harvest system from stump to loaded on a truck in the Arena simulations. Arena also provided instantaneous utilizations for all simulated harvesting machines. In the simulation, the feller-buncher was busy 54% of the time, one skidder was busy 78% of the time while the second was busy 69% of the time, and the loader was busy 23% of the time. Utilization rates in the Auburn Harvest Analyzer model were 54% for felling—the same as our simulation. AHA's utilization rate for the skidding function was 70%, and the skidding resources used in the simulation were busy on average a close 73.5% of the time. The loading procedure was utilized 26% of the time according to AHA's model, again close to our 23%. These utilization differences are minor and support the processing times programmed into each harvesting operation used in the simulation.

The simulation was run for two time periods to authenticate short-term and long-term production levels. To define a week in terms of hours worked, we adapted Hahn's [2] logging survey respondents in eastern North Carolina, and used an average of 49 hours worked per week. According to the survey, logging firms in eastern North Carolina produce 2960 tons of roundwood per week. After running

DOI: http://dx.doi.org/10.5772/intechopen.85412

			COASTAL PLAIN TOTAL OUTPUT							
			**From TPO data & TMS Weight Equivalents							
	in Cubic Feet									
	All products		Sawlogs		Veneer logs		Pulpwood		Other industrial	
	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard
All counties	**313,118,000**	**54,145,000**	**125,012,000**	**14,433,000**	**27,115,000**	**5,810,000**	**146,942,000**	**32,762,000**	**14,049,000**	**1,140,000**
	Cubic Meters (m^3)									
	All products		Sawlogs		Veneer logs		Pulpwood		Other industrial	
	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard
All counties	**8,866,431**	**1,533,201**	**3,539,912**	**408,693**	**767,804**	**164,519**	**4,160,895**	**927,708**	**397,820**	**32,281**
	Short Tons (2000 lbs)									
	All products		Sawlogs		Veneer logs		Pulpwood		Other industrial	
	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard
All counties	**10,786,412**	**2,241,439**	**4,306,463**	**582,836**	**934,068**	**231,580**	**5,061,916**	**1,382,549**	**483,965**	**44,475**
Other industrial: Includes composite panels, poles, posts, mulch, log homes, industrial fuelwood, and all other industrial products.										
Total Pine & Hard (tons)	**13,027,851**									

Table 6.
Timber product output weight equivalents, coastal plains total (tons).

the simulation for 49 hours, 2810 tons were produced, again a minor difference, of 150 tons per week. In terms of softwood and hardwood production, 2136 tons of softwood are produced and 674 tons of hardwood are produced.

According to Hahn's [2] survey, a logging crew in eastern North Carolina produces 147,975 tons per year. When we ran the simulation for 2450 hours, the harvesting model produces an annual total of 147,097 tons, a minor difference of 878 tons per year. The simulation model produced 111,793 tons of softwood and 35,304 tons of hardwood on an annual basis.

These production levels along with historical timber output reports, harvest distributions, employment metrics for the logging industry, and market forecasts for timber demand growth were used to analyze logging capacity.

Total timber output in both the USDA Forest Service Forest Inventory and Analysis (FIA) coastal plain regions in 2011 was 13,027,851 pine and hardwood tons, with about 83% of all harvests were pine according to the Forest Service Timber Product Output (TPO) report and about 76% of harvests were pine according to the Forest Service on-line annual timber removals package (FIDO), as summarized in **Table 6**.

Logging employment levels for North Carolina's forest products industry were obtained from tables of the Bureau of Labor Service [34]. In the fourth quarter of 2014, employment in the northern coastal plains' logging industry (NAICS 113310) totaled to 380, up from 236 in 2012. Conversely, logging employment in the southern coastal plain (NAICS 113310) was 344 during the fourth quarter of 2014, down from 372 in the first quarter of 2012. Labor force totals for the logging industry in the coastal plains equal 724, up from 608 in the first quarter of 2012.

Logging crew compositions vary among geographic regions. To gain an estimate of "in-woods" crew sizes, we consulted previous studies and logging surveys. According to Hahn's [2] logging survey, the average number of total employees per logging firm in North Carolina is 16 with a minimum of 2 and a maximum of 30, but this included multiple crews per firm. Baker et al. [22] found average crew sizes to be 4 and 4.2 employees via surveys and face-to-face interviews respectively. Finally, Barrett et al. [31] surveyed logging operations in Virginia's coastal plain and found average crew sizes to be 4.2 employees. Thus for the Coastal Plain, we chose to use an average crew size of 4.2 employees. Further, at the average 2011 Coastal Plain timber output levels of 13,027,851 pine and hardwood tons, and our simulation results of 147,097 tons to represent annual production levels of a typical logging crew in eastern North Carolina, then in 2011 it would have taken approximately 89 crews to supply TPO levels of wood. At 4.2 employees per crew, we estimated that 372 in-woods logging employees could supply the total production output for the North Carolina Coastal Plains in 2011.

Based on timber supply and demand projections from The Southern Forest Futures Project [32], three linear growth scenarios were developed and applied to analyze the sensitivity of the logging workforce to different rates of growth. The first scenario represented an additional 1.2-million-ton growth annually in timber output, or 0.5%. In scenario two, timber output increased by 1.289 million tons annually, or 1.0%. The third scenario increased at 1.5% per year, or 1.378 million additional tons annually. Under a 0.5% growth rate in timber output, an average of 8.2 additional logging crews or 34 logging employees will be needed each year to produce this level of output. At a 1.0% growth rate, an average of 8.77 additional crews per or 37 loggers will be needed each year to meet growth in production. Under a 1.5% growth rate in timber production, an additional 9.37 crews or 39 logging employees on average will be required each year over the 10-year period. Finally, to provide a "loggers required per million tons" metric, we estimate that an additional 29 "in-woods" employees (6.8 crews) are required each year to produce an additional 1 million green tons.

4. Discussion and conclusions

This chapter synthesizes several timber harvesting research threads and principles in the Southern Cone of South America and in North Carolina in the U.S. South, based on detailed empirical survey, economic, and simulation approaches. The research summarized here estimates timber harvesting productivity and costs in Southern Cone and in North Carolina; reviews the current literature about Southern U.S. timber harvesting productivity and costs; and provides unique components on innovation in the Southern Cone and on timber harvesting capacity in North Carolina. As such, the chapter provides a handy combination of current timber harvesting research, theory, and applications that can be useful for comparisons of comparative advantage between the U.S. South and the Southern Cone of South America, and provide benchmarking for logging and forest products firms, further research, or for policy considerations.

Some generalizations can be made about each of the possible international comparisons. Logging production data were calculated by each of our studies, and widely available in the literature. Cost data are reported in the Southern Cone research and the North Carolina survey, and some is available in the literature for both broad regions. The innovation research such as in our work in the Southern Cone is less common, but some comparisons can be made with other literature, and some insights can be drawn from our North Carolina research. Logging capacity has been talked about quite a bit, but our study in North Carolina is the only empirical example we found.

First, timber harvesting production rates have continued to increase along with mechanization for decades [35]. Carter et al. [16] reported the highest mechanized feller-buncher grapple-skidder system had average logging production rates of 2600 tons per month, or about 30,000 tons per year in 1990 in the U.S. South. By 2007, Baker and Greene [17] reported average production rates in Georgia of 5800 tons per month, or about 70,000 tons per year. By 2014, Hahn [2] found that logging firms in eastern North Carolina produce 2960 tons of roundwood per week, and work 49 weeks per year. Thus the North Carolina average firm production was 145,000 tons per year or 12,000 tons per month. Baker et al. [22] reported average weekly production among 22 firms in the South to be 4197 tons, which would be about 200,000 tons per year or 17,000 per month.

These average U.S. South production rates were usually on a per crew basis, but still were considerably less than the average rates of more than 300,000 tons per year per firm in Brazil and Uruguay in 2012. This is somewhat surprising that the Southern Cone is more productive, but reasonable upon reflection. Perhaps the biggest driver for this is that almost all timber harvesting in the Southern Cone is occurring in planted Southern U.S. pine species (e.g., *Pinus taeda*) or eucalyptus stands, which have much higher growth rates and much higher stand volumes per unit of area at harvest than in the planted and natural stands in the U.S. South—perhaps two to three times more volume per area at final harvest [10]. At least half of U.S. South timber production and logging still occurs in natural stands, which are less uniform and have lower stand volumes at harvest. Thus it would be easier to achieve high production rates with more wood volume per turn for machines and for systems. The reported production rates in South America also may include some multiple crews and multiple shifts per firm, which is not the case in most of the U.S. data.

As the productivity rates would suggest, timber harvesting costs per ton for the Southern Cone were usually less than in the U.S. South. For their logging cost index in the U.S. South, Baker et al. [25] set the initial cut and load at roadside logging value in 2011 as US$ 12.50 per ton. Hahn [2] found that reported cut and load logging contract rates in North Carolina (which presumably include some profit, so should be higher than logging costs) were US$ 13.74 per ton. These values were somewhat greater than those found in most of the production in the Southern Cone for about the same period—US$ 7.41 per ton in Argentina, US$ 8.19 per ton in Brazil—although less than the $14.82 per ton in Uruguay.

The rank of this difference makes sense since productivity rates are higher in the Southern Cone, if the equipment fixed and operating costs are similar in all countries. Uruguay costs probably were somewhat greater because they did use more expensive full timber processor/forwarder equipment, and had high fuel costs as well. The higher timber production volumes per area at harvest and the use of multiple shifts help drive these higher logging productivities and lower logging costs. While we do not review logging transport costs here, they too are problematic in both the U.S. South, where it is hard to find drivers who meet the strict license requirements, and in the southern Cone, where transportation networks often are not very good.

Mac Donagh [15] analyzed the role of innovation specifically in the performance of logging firms in the Southern Cone. That study showed that that the mechanization and innovation process there has been through the diffusion and adoption process throughout much of plantation forestry sector in the Southern Cone, and that good management will lead to better outcomes and more profits there like developed countries in the northern hemisphere. Loggers that had mutualistic, cooperative relations with contracting pulp and paper companies had the highest production rates and the lowest production cost per ton—which was the opposite of findings in more developed countries. Mechanization with the highest technology produced the highest production output levels.

Logging innovation capacities were more important than the business skills for production and growth. Innovation was more important than just buying the newest equipment in determining firm success [15]. In both the Southern Cone and in the study by Stone et al. [14] in Maine, the research found that the most successful logging contractors were the best innovators in products or process, followed by market innovation.

The last research focus on timber harvesting and logging capacity in this chapter was only directly investigated by Roll [26], although we can infer much about this question from other research and popular articles. In brief, there are pervasive concerns that as the forest products manufacturing sector expands, at least in the U.S., there will not be enough loggers to harvest all the wood needed [36]. Timber harvesting is hard, dangerous, and the pay is relatively modest. Surveys by Hahn [2] and Baker and Greene [17] and Greene et al., [19–21] indicate that both the average age of loggers, and often the age of their equipment, is getting much older.

While the logger demographics are disconcerting, there were high production levels in North Carolina as found by Hahn [2], and corroborated by the simulations of Roll [26] and others in the South. Roll determined that a relatively modest number of 30 employees and seven harvesting crews of four in-woods persons could harvest an additional 1 million tons of wood in the Coastal Plain of North Carolina. However, this is only an 8% increase based on 13 million tons of production in the state; large production increases could require many more workers quickly.

We conclude that an expansion of the number of logging crews—which can harvest from 150,000 to 200,00 tons of production per year—would most likely come from expansion and innovation from existing logging firms, not completely new entrants to the business, or from wood dealers who serve as middlemen in the procurement process in Eastern North Carolina. Thus an expansion of moderate amounts of timber harvesting production at the margin does not seem insurmountable, although several million tons or more of production would become increasingly harder to achieve by merely expanding current, often undercapitalized, logging firms. Innovation to achieve higher productivity would be important in this case.

While not examined specifically, we believe it would be easier for logging companies in the Southern Cone to expand to achieve higher logging production to supply forest products manufacturing facilities. The logging production rates exceeding 300,000 tons per year were higher than in the U.S. South; the work is still perceived comparatively favorably by rural workers in the Southern Cone; and there are fewer rural manufacturing or service alternatives to timber extraction.

Overall, these linked studies of timber harvesting/logging in the Southern Cone of South America and the U.S. South are very informative. While the timber harvesting productivity rates and costs were not far apart, the Southern Cone generally had a competitive advantage, with observably higher logging production rates and lower logging costs. Timber harvesting technology and innovation had matured considerably in the Southern Cone in the last two decades. The studies reviewed here suggest that average logging cut and haul rates were perhaps $3–$5 per ton cheaper in the Southern Cone, which multiplied by one quarter to a million tons per sawmill or pulp mill, adds up to a considerable cost advantage per mill, and for South America.

In addition, the timber plantation growth rates, final harvest yields, and investment returns for stumpage alone also are much better in South America than the U.S. South [10]. Cheaper fast grown timber plantation costs and timber harvesting production and cost advantages unite to provide substantial competitive advantages throughout the value chain to Southern Cone planation forestry. These countries of course have considerable challenges and more variable macroeconomic factors, political risk, poor roads and infrastructure, and other issues, which constrain their excellent forestry opportunities.

However, if the underlying institutional fundamentals do align well, the Southern Cone can grow and harvest wood cheaply, and will continue to expand forest products mills and harvesting capacity more quickly as well. This trend is evidenced by the opening of many new pulp and paper mills in the Southern Cone over the last few decades, while a large number have closed in the U.S. South. The Southern Cone roundwood production increased about 25% from 171 million m^3 in 2008 to 217 million m^3 in 2017 [5, 6], while that in the U.S. South was relatively flat at about 185 million m^3 [7]. The South still has the most forest manufacturing production capacity in the world, but has a decreasing total output share, which is likely to continue based on the timber harvesting costs examined here, as well as timber plantation production and cost advantages in the Southern Cone.

Acknowledgements

Partial funding for the research on was provided by the USDA Forest Service Southern Research Station; by the NC State University Southern Forest Resource Assessment Consortium; and by the respective organizations of the co-authors. Karen Abt of the USDA Forest provided insightful review comments for the manuscript.

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