ABSTRACT

CREEKMORE, LAWSON TODD Modeling Timber Supply from Planted Forests in Selected South American Markets: Applications of the SRTS Modeling Framework. (Under the direction of Dr. Fred Cubbage).

Current public information about timber and forest markets is modest and timber market information that is comprehensive and well synthesized for decision making is rare. This information for markets in South America is even scarcer. Timber market modeling approaches are reviewed. The Sub-Regional Timber Supply (SRTS) modeling framework and its merits for exploratory applications in South American plantation markets are discussed. Case studies of *Eucalyptus grandis* in Uruguay, *Eucalyptus spp.* in Brazil, and *Pinus taeda* in Brazil are investigated. The harvest exogenous mode of the SRTS model shows promise as a gap analysis tool, identifying short-term price spikes. The price exogenous mode of SRTS provides estimates of likely future harvest levels. Efforts are inhibited by the amount and quality of data available. There is a need for inventory data for Brazil disaggregated by region and management type.

Modeling Timber Supply from Planted Forests in Selected South American Markets:
Applications of the SRTS Modeling Framework

by
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CHAPTER 1-
Introduction and Methods

Forest land investors and forest products firms need good information about timber supply, demand, and prices in order to assess their forest investments. These needs include information for allocating resources among timber production and land development, decisions concerning levels of management intensity, negotiating timber sale and long term leases, deciding whether to purchase or sell forest land, and whether to pursue domestic or international investments.

Current public information about timber and forest markets is modest, and timber market information that is comprehensive and well synthesized for decision-making is rare. Periodic national and regional assessments provide snapshots of market conditions, but are usually dated by the time they are published. The input assumptions change rapidly, the basic forest inventory data are updated continually, and regional, national, and international factors vary significantly.

The Southern Forest Resource Assessment Consortium (SOFAC) at North Carolina State University (NCSU) was created to examine these issues in southern U.S. timber markets and international investments through regional timber supply modeling in the South, with extensions to the U.S. and world. SOFAC developed a portfolio of timber supply models centered on the Subregional Timber Supply (SRTS) model and related land use, timber demand, and investment models (Abt et al. 2009, 2010). These have been complemented by international timber investment analyses (Cubbage et al. 2007, 2010) and many related applications and studies.

South America Timber Supply Model

South America has been the fastest growing timber supply region for production of industrial roundwood in the last five decades. It has increased its share of total world timber production from 3% in 1960 to 10% in 2005. This translates into an increased level of production from 20 million cubic meters of roundwood in 1960 to about 180 million cubic meters in 2005 (Gonzalez et al. 2008).

This project is part of a plan for a new line of research that we plan to perform in the SOFAC cooperative program, specifically building a timber supply model and trade model for South America to complement the SRTS model for the U.S. South. This research specifically addresses Objective 1 of the 2012-2017 SOFAC Study Plan:

(1) Develop and apply enhanced southern timber supply models to assess forest conditions and prospects, in relation to national and world timber markets. Continue to develop and apply enhanced southern timber supply models through the SRTS framework to assess forest conditions and prospects, in relation to national and world timber markets.

All of the global timber supply and demand models to date are aggregate global trade/general equilibrium models for all countries in the world, using aggregate FAO data on world forests and production. Furthermore, they are long run dynamic programming, optimal control, or econometric models that assume that wood producers are all economically rational, and will maximize net returns and consumer and producer surplus in the long run by shifting timber production to the most profitable countries.

This research followed a different approach, which developed a South America Timber Supply Model, based on the SRTS framework and detailed forest inventory inputs. The SRTS framework is an empirical forest inventory/stand table projection/economic implications model, which is driven by timber inventory, then linked to economic implications and responses (Abt et al. 2009). For foresters, these models might be characterized as stand table projection models as the core biological drivers, then with economic supply and demand added via the use of elasticities in order to determine the price, quantity, and inventory/area change effects of those stand table projections.

This approach can be contrasted with the global general equilibrium models in that our models will (1) seek to use better forestry data for each country; (2) be focused on empirical forest inventory, growth, and removals data rather than on econometric estimates of timber supply and demand; (3) focus on the medium term—10 to 30 years, rather than very long run projections; and (4) use a partial equilibrium approach rather than a global approach.

Hypotheses

This research approach examined several key hypotheses:

H_1: The joint SRTS southern U.S. and South America models will provide better projections of timber supply in both regions than the global general equilibrium models.

H_2: The collection and use of detailed, fine scale data on timber area, inventory, growth, and removals in the SRTS framework will lead to better projections of timber supply in both regions of the Americas than the global general equilibrium models.

H_3: The fine scale SRTS South America model can provide a useful new management decision making tool for investors and companies there.

H_4: The fine scale SRTS South America model can provide a useful tool for national timber supply, carbon accounting and REDD projects, and policy analyses.

H_5: South America will continue to increase its timber supply and global shares of industrial wood production and related forest products industries.

These are refutable hypotheses, but we offer them as promising prospects that justify the merits of building new approaches for South America, linked to our research results in the U.S. South. We hope to cooperate with individuals in most of the key South American countries in order to collect the data and build the models needed to assess these questions.

Methods

The first step in this new direction of research was to investigate the utility of the SRTS model for use in several South American markets with differing levels of data availability. Readily available, high quality data was very hard to come by in South America. This stands in contrast to the United States, where highly disaggregated and specific inventory and harvest data are available to the public from regular FIA assessments through the USDA Forest Service. The SRTS model was designed to use these data sets as inputs, so the goal for these preliminary investigations will be to find out if the SRTS model can be adapted and still serve as a useful decision making tool in less data-rich situations.

Relationships have been established with forestry professionals throughout the South American region, and we have sought high quality data for each important timber producing nation. These efforts have yielded many promising relationships with prospects for future cooperation and have produced sufficient data to investigate markets in two countries, Brazil and Uruguay. The exercise is a good one, as each country provides a unique scenario.

We developed this research with Co-Principal Investigators (Co-PIs) in Uruguay and Brazil. They included Alvaro Perez del Castillo of Pike & Co. and Adriana Bussoni of Universidad de la Republica in Uruguay, Bruno Kanieski in Brazil, as well as Robert Abt, Fred Cubbage, and Jesse Henderson at North Carolina State University.

In Uruguay, the partnership produced high quality nation-level data of plantation inventory and wood fiber demand. The timber market in Uruguay is very young, so the situation is one of industry infrastructure still being established in order to fully utilize the existing inventory.

In contrast, data for Brazil was less readily available. Inventory and silvicultural information had to be mined from several public reports of a wood industry cooperative organization called ABRAF. Through some basic assumptions and inferences, we were able to build an adequate data set for analysis using the SRTS model framework. Brazil also differs from Uruguay in that the timber market is well established, it is already an important global player, and it is geographically much larger than Uruguay. The much larger area makes the absence of regionally disaggregated inventory and demand data more of a concern with useful market analysis.

Even with the challenges and limitations of current data availability, our hypothesis is that the SRTS model framework can prove to be a useful tool in South America for forest products companies, forestland investors, and policy makers alike. The SRTS model provides the most valuable market simulations available for the US South, and if this capability can be eventually extended to South America, then the model could provide a detailed explanation of two of the most important industrial wood producing regions in the world. A secondary goal is to simply examine the current forest plantation situations in Brazil and Uruguay through the process of data collection and examination.

I will discuss timber supply modeling and the differences between approaches. Then, I will present major modeling approaches from the literature from a historical perspective, which will provide context for introduction of the SRTS modeling framework and its use in our initial explorations in Latin America. Several survey-containing studies have been useful, such as Binkley (1987), Wear and Parks (1994), Pattanayak, Murray, and Abt (2002), and Latta and others (2013).

CHAPTER 2-

Review of timber supply modeling approaches and SRTS model background

Timber supply modeling provides the essential link between the biology and ecology of forest resources and the economy. Understanding timber supply is an essential tool in public policy for evaluating trade-offs between forest production and the environment, forecasting timber market activity, and assessing the level and distribution of costs and benefits of forest policies (Wear and Pattanayak 2003). Outside of the public sector, timber supply modeling is important to the forest products industry, whether it be a company planning future operations in an area or investors deciding where and how to do business. The critical challenge of timber supply modeling is constructing theoretically valid and empirically practical aggregate description of harvest behavior (Wear and Pattanayak 2003).

Binkley (1987) described timber supply models as having developed along two lines: long-run, theoretically robust models and short-run empirically practical models. Wear and Parks (1994) describes the two schools as normative, engineering approaches and positive, statistical approaches, respectively. In a long-run, engineering approach agents will optimize the net present value of the resource throughout the time horizon, normalizing the structure of the forest resource to achieve peak efficiency. This approach can be very useful for making long-run forecasts and characterizing the general long-run dynamics of a forest resource, but it provides information about events well beyond the planning horizon of many decision makers. Its forecasts cannot be trusted as a forest resource transitions from its initial condition toward a steady-state situation, which can take decades.

The statistical approach, however, is much more useful for short-run analyses of different economic hypotheses. The statistical model is generally structured based on theory of rational behavior and estimated using observed, historical data, which makes these types of models much more trustworthy for the types of short-run analyses required by many market agents. These models, however, are calibrated to reflect the way in which market prices and harvest levels relate to the structure of the forest resource at a particular point in time. This relationship can change over time. “An inventory skewed towards newly planted forests is qualitatively distinct from the same level of inventory represented by old growth forests or a bimodal age distribution” (Wear and Parks 1994). The positive, econometric models lack explicit links to production technology and the dynamics of forest capital, and in the long-run these types of models yield power to the long-run optimization models. As follows, long-run, dynamic optimization models have been widely used, for example, in the analysis of climate change mitigation strategies (Songhen and Sedjo 2005, Sedjo and Sohngen 2000), while econometric models have traditionally been used to model short term price effects and the direct effects of tax policies.

The modern era of market level timber supply modeling began mainly as a response to public policy. The event that initiated the use of forest sector models in public policy in the United States was the passage of the Forest and Rangeland Renewable Resource Planning Act of 1974, or RPA. The RPA requires a periodic assessment of supply and demand for the renewable resources and amenities provided by the nation’s forests.

The Timber Assessment Market Model (TAMM) (Adams and Haynes 1980) was the fulfillment of the need for a national level timber market assessment tool. The TAMM collaboration between Adams and Haynes was the logical next step after the preceding decade which saw both Adams and Haynes independently become leaders in the econometric modeling of timber markets (Adams 1974, Haynes 1975). TAMM is a spatial, econometric model of the solidwood and timber inventory elements of the US forest products sector, and provides annual projections of volumes and prices in the solidwood products and sawtimber stumpage markets and estimates of total timber harvest and inventory by geographic region for periods up to 50 years (Adams and Haynes 1980, 1985, 1996).

TAMM, in conjunction with the ATLAS model of timber inventory (Mills and Kincaid 1992), became one of the most widely used tools for forest policy analysis in the United States, and was used for the periodic RPA analyses until 2010. This was done with various adjustments and updates, of course (Adams and Haynes 1996). Not restricted to public policy use, TAMM has also been used by various public agencies, private firms, and environmental groups to examine issues ranging from log export policies to the impacts of carbon sequestration through tree planting (Adams and Haynes 1996). The TAMM model dealt mostly with the solid wood sector, so a parallel model was developed for the pulp and paper industry, initially referred to as PAPYRUS (Gilless and Buongiorno 1987), and afterward as the North American pulp and paper model (NAPAP) (Buongiorno 1996).

Another important model from the 1980s was the International Institute for Applied Systems Analysis Global Trade Model, or IIASA GTM (Kallio et al. 1987). A similar model formulation to that of Adams and Haynes, and with mathematical similarities to the PAPYRUS model, the GTM was the first global forest sector model. The IIASA GTM had a mid-range projection period and was formulated to allow runs of up to 50 years in 5 year steps. The original IIASA GTM has served at the basis for various regional timber market models, such as the SF-GTM in Finland (Ronnila 1995), the Norwegian NTM model (Tromborg and Solborg 1995, Bolkesjo and Solberg 2003), and the ATM for Austria (Kornai and Schwarzbaur 1987). The European Forest Institute GTM, or EFI-GTM, was essentially an update to the IIASA GTM with more disaggregated regions and production technologies (Kallio et al. 2004), and has been used for recent European forest sector analyses (UNECE 2011).

With several additions and adjustments, the Center for International Trade in Forest Products at the University of Washington produced the CINTRAFOR Global Trade Model (CGTM)(Cardellichio et al. 1988). The CGTM model has been used for many global analyses by CINTRAFOR (Perez-Garcia and Marshall 2002, Perez-Garcia et al. 2002, Perez-Garcia 1993).

The Forest and Agriculture Sector Optimization Model (FASOM)(Adams et al. 1996) is a dynamic, nonlinear programming model of the forest and agricultural sectors in the United States. The FASOM model was developed in order to assess and compare different climate change mitigation strategies, such as strategies to increase carbon sequestration in US forests (Adams et al. 1996). Central to FASOM is the analysis of changes between agricultural and forestry land uses by pairing a TAMM-based forest sector model with an agricultural sector model (ASM, Chang et al. 1994). The model provides estimates of economic welfare disaggregated by agricultural producers, timberland owners, consumers of agricultural products, and purchasers of stumpage (Adams et al. 1996). The FASOM model uses a nonlinear mathematical programming approach with intertemporal optimization. Farmers and private timberland owners are assumed to have perfect foresight regarding the consequences of their behavior; that is, expected future prices and the prices realized are identical (Adams et al. 1996).

Fitting the model for use in Europe has resulted in the European Forest and Agriculture Sector Optimization Model (EUFASOM) (Schneider et al. 2008). EUFASOM has been used to examine the effects of the price for fossil fuel CO2 emissions on the use of wood in Europe (Lauri et al. 2012).

Another normative, engineering approach using intertemporal optimization is the Timber Supply Model (TSM) (Sedjo and Lyon 1990) that also developed into the Pulpwood Supply Model (PSM) (Sedjo and Lyon 1996). The TSM/PSM model is a global, long-term model that uses optimal control programming to solve the model for all time periods simultaneously, implying perfect foresight. The model is a useful vehicle for systematizing and formalizing the factors that affect long-term supply as well as examining the nature of the forces and the interrelationships within and among supply regions (Sedjo and Lyon 1996).

Expanding on the efforts by Sedjo and Lyon (1990,1996), Songhen, Mendelsohn and Sedjo (1999) produce another forward-looking dynamic model of global timber markets (GTM). It differed from the previous efforts by including more global regions, endogenizing forest investments for future supplies in all regions, and capturing a complex description of stand ages in order to endogenize standing inventory in forest decisions (Songhen, Mendelsohn and Sedjo 1999). Songhen and Sedjo (2006) used their optimal control approach once more to investigate carbon sequestration and energy abatement to determine the potential role of forests in greenhouse gas mitigation.

Another important international forest sector modeling effort is the Global Forest Products Model (GFPM)(Buongiorno 2003). In order to discuss the context and approach of the GFPM, it is necessary to begin with the PAPYRUS model of the pulp and paper industry (Gilles and Buongiorno 1987) that was developed for the USDA Forest Service to assist in the Timber Assessments required by the Resources Planning Act. The engine behind the

PAPYRUS model was software called the Price Endogenous Linear Programming System (PELPS), and after progressive improvements, the PELPS IV (Buongiorno et al. 2003) software formed the structure of the GFPM model (Buongiorno 2003). The PELPS approach has static and dynamic phases, which correspond to short term market equilibrium and changes in market equilibrium over time, respectively (Buongiorno 2003).

PELPS uses a hybrid of linear programming and econometrics methods in the static phase. The dynamic phase uses methods similar to system dynamics, but with equations based on economic theory. Perfect foresight of decision makers and global optimization over extended periods of time are *not* assumed (Buongiorno 1996). This is in contrast to the optimal control methods like those employed by Sedjo and Lyon (1990). The purpose of the GFPM is to compare results from different scenarios to assess the likely magnitude of changes in forest sector variable resulting from policy, macroeconomic shocks, or management decisions. The earliest applications of the framework were for Southeast Asia before it was applied to the global market and trade (Buongiorno 2003) and was used for the UN FAO’s Global Forest Products Outlook Study (Zhu et al. 1998).

It was previously mentioned that the TAMM/NAPAP framework (Adams and Haynes 1980, 1985, 1996) was used in all RPA assessments until the 2010 assessment. The US Forest Products Module (USFPM) (Ince et al. 2011) was developed specifically for the 2010 RPA assessment. The USFPM operates within the GFPM to provide long range timber market projections for the United States in relation to global economic scenarios.

In Binkley’s (1987) review a call was made for more of what were referred to as transition models. That is, models that marry the short-run and long-run approaches to provide a more complete characterization of the forest resource, providing the advantages of both theory and empiricism. A recent review by Latta and others (2013) published 26 years later mentioned a need for more models that harmoniously employ both approaches. Binkley also called for more attention to be paid to land markets and forestry's competing land uses. These needs of the past have been met in part by models like the FASOM model, which combines TAMM-based, econometric timber supply with intertemporal optimization of land use changes between forestry and agriculture and assumes perfect foresight on the part of the landowner.

Common to many past reviews of modeling approaches (Binkley 1987, Parks and Wear 1994, Pattanayak et al. 2002) is the recognition of the need for models that can not only account for the heterogeneous quality and characteristics of the forest resource but also the various motivations of different forest landowners. This is particularly important in the US South, where the vast majority of forestland is held by private landowners that, in most cases, are not maximizing profit, but utility. Pattanayak et al (2002) reviews literature and presents an empirical modeling framework for modeling timber supply from utility maximizers. A model needs to at least be able to recognize the differing relationships that forestland held by different landowners have to the market. To Binkley (1987) this was a problem of insufficient data.

An issue with all of the widely-used models mentioned previously is one of geographic resolution. Of course, one's objectives define whether something is a problem or not, however most investment and management decisions are made on a much finer scale than what is reflected by the models generally used for policy analysis. Even seemingly general policy questions often need a much finer geographic resolution in order to understand the full implications of an issue. This was a problem in the US South, which is one of the most important industrial wood producing regions in the world, but has been represented in every other widely used model as one (at most two) supply regions.

South America is a very important industrial wood producing region, and is becoming more important all the time (Gonzalez 2008). It is also one of the most profitable regions to grow timber (Cubbage et al. 2007, 2010, 2014). However, in the global timber supply models South America is treated as one supply region or represented by one of its countries. Also, many global analyses use long-run, dynamic optimization approaches which don't provide empirically useful results for decision makers. The SRTS model could be useful for South America as is has for the US South, and the ability to link the regions would provide opportunity to analyze together two of the most important supply regions in the world at fine detail.

SRTS Model Background and Adaptations

The Subregional Timber Supply Model (SRTS) (Abt et al. 2000, Abt et al. 2009) was developed for use in the US South in response to the limited geographic resolution of all other model approaches mentioned above—specifically the TAMM/ATLAS approach that was employed by the USDA Forest Service for RPA assessments. All previous modeling efforts had treated the US South as a homogenous supply region, while the reality is that timber supply patterns and responses are much more complex and heterogeneous in the South. Many management and policy decision makers need information on the subregional level, as this is the level at which most decisions are made. The timber stumpage market is limited to subregional units naturally, due to transportation costs. Prestemon and Abt (2002) used the SRTS model to project timber supply in the Southern Forest Resource Assessment

(SOFRA). Adams et al. (2005) compare the results of the SOFRA study to results of the fifth RPA assessment for the South (Haynes 2003).

The SRTS model combines two different modules: a biological inventory projection model developed based on the GRITS model (Cubbage et al. 1990) and a conventional supply and demand framework. The goal of the model is to link timber market economic feedbacks with forest resource dynamics. The result, in theory, is a forecast of future market conditions that is not only economically reliable, but biologically correct and feasible.

The SRTS model's market and inventory modules both inform a goal program, which in turn allocates a year's harvest across standing inventory based on historic harvest patterns. Changes to the inventory component based on a year's harvest levels not only change the following year's available inventory, but feed market level changes to price (and so demand) based on elasticities specified exogenously by the user. This pattern is followed throughout a mid-range (30 year) term. Figure 2 shows standard data flows in the model. Further, detailed reading on the current SRTS model's specifics can be found in Abt et al. (2000, 2009). The most recent version of SRTS has the capability of endogenously projecting land use changes (Abt et al. 2009).

The SRTS model has three different 'modes' for analysis. These modes refer to which input is exogenous and are called "harvest", "demand", and "price". In the harvest mode, the demand assumptions specified exogenously by the user are understood as the quantity of harvest directly, without regard to market effects. This mode would be most useful in a market that has a high level of vertical integration with plantations owned by companies whose purpose is to keep mills running at full capacity. SRTS tracks the implied price and inventory effects, but the model will not be allowed to endogenously adjust the level of harvest each year. It is read directly from an input file. We used this mode in the preliminary runs in Brazil and in Uruguay because of the vertically integrated market structure.

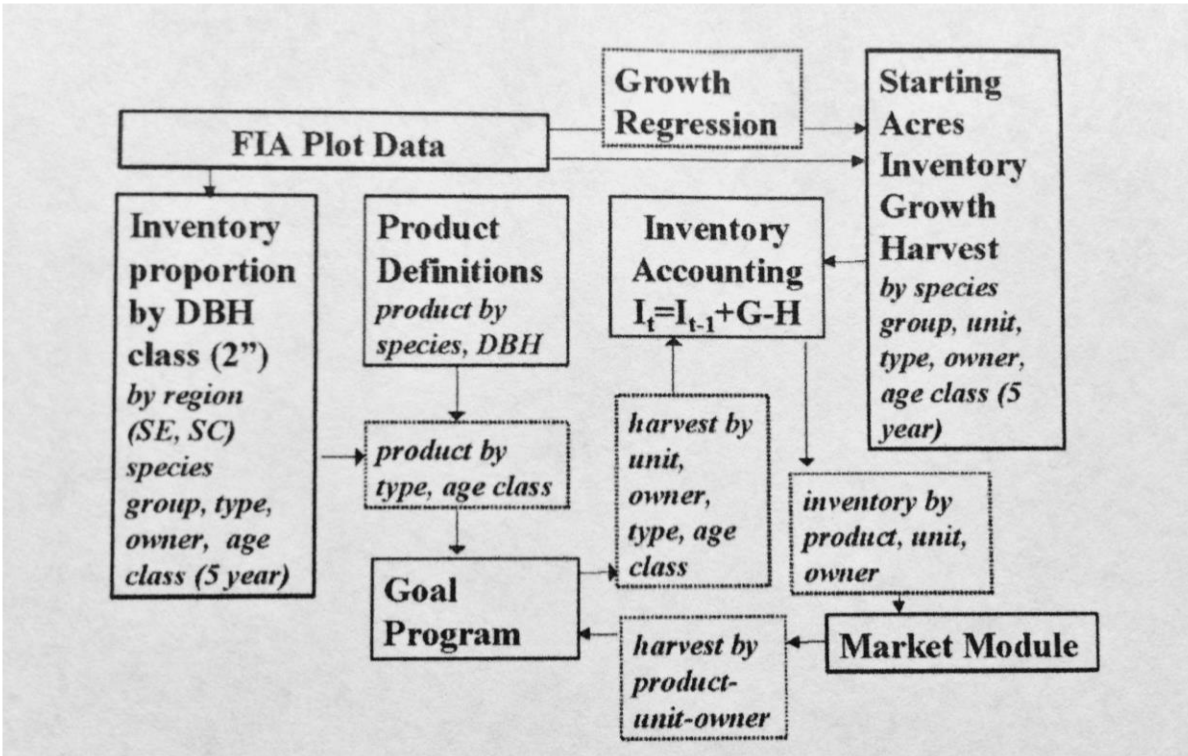

Figure 2.1. SRTS data flows (Abt et al. 2009)

In the demand mode, the demand assumptions are treated as just that: demand. This means that quantities of demand specified exogenously are more flexible and can adjust based on market effects throughout the projection period. This is the most often used mode for runs in the US South, where there is a horizontally integrated market dominated by non-industrial, private timberland.

The price mode, as will be shown, proved to be the most useful tool for analysis in Brazil and Uruguay. In this mode, price is specified exogenously by the user, and the model tracks the removal levels that would be necessary, given the inventory structure, to achieve the specified price. This would allow the user, for example, to assume current equilibrium and project the implied demand trajectory. Intuitively, this would provide an estimate of how much "room" there is in the market, as demand increases above or below the equilibrium trajectory would imply price effects. This mode essentially tells the analyst how much timber demand or wood use would be needed to keep prices at a given level. This would be helpful in these newly developing regions where the plantations came first, but the demand is uncertain.

Some adaptations were made to the model in preparation for exploratory runs in South America. Adjustments made to the SRTS model can be thought of as simplification and were the result of differences in biological characteristics, market structure, and data availability.

Faster growing plantation species in most of South America require shorter rotation lengths, so we used two year age classes for South American runs as opposed to the five year age classes traditionally used in the US South.

The majority of important forest plantation owners in South America are large companies with vast holdings, which behave very similarly. In Uruguay there exists essentially one type of forest land owner (industrial) among whom management styles are identical, the market is integrated fairly vertically, and forestry activities are only allowed on land classified by the government as approved for forestry (or sufficiently inadequate for agriculture). In the US South, inputs and results are disaggregated by ownership (industrial vs. non-industrial) and management type, allowing for disparities with respect to elasticities and growth rates. This was not deemed necessary for our preliminary South American runs and was not possible with available data.

The SRTS framework was originally developed to work in conjunction with detailed, region-specific FIA inventory and harvest data published in the United States by the USDA Forest Service. The level of specificity and disaggregation available in FIA data is not found in data sets available for South American countries, so naturally this reduces the amount of variables included and simplifies the type of analysis that can be done. One of the SRTS model's greatest assets is the ability to project shifts in production between regions and landowners. This type of analysis could not be done with available data for the smaller regions in South America.

The next two chapters show the results of the application of the SRTS model in Uruguay and Brazil. The last chapter draws conclusions about the use of SRTS in South America or other newly developing forest plantation economies.

CHAPTER 3-
SRTS Application: Uruguay

Introduction

Uruguay is a small country positioned between the two giants of South America: Argentina and Brazil. Its territory covers an area of 17.1 million hectares with a population of 3.3 million inhabitants. Approximately half of those inhabitants live in the capital city, Montevideo. The main industries of the country are agriculture and cattle (WFC 2002). In a "market brief" published in 2002 by the World Forestry Center it was noted that Uruguay had the potential to be an important forestry country due to its location, fast growing tree plantations and governmental support for forestry activities. Between 2002 and 2010, the volume of timber harvests in Uruguay had tripled (Olmos 2011).

The roots of the timber industry in Uruguay can be traced back to the Forestry Law created in 1987. Based on a previous law established 19 years prior, it promotes the establishment of large scale forest plantations; and it worked. Afforestation between 1989 and 1992 was eight times greater than the average annual rate from 1979 to 1988 and currently there are more than a million hectares of productive forest plantations (Switzer 2014). The majority of plantations are established by a few main players in the market: UPM Uruguay, Weyerhauser and Montes del Plata (Olmos 2011).

Following the supply, large pulp mills began appearing in 2003 and new projects have continued to be established as the infrastructure catches up with the large expansion in planted area. Information from Pike and Co. suggests that major infrastructure building will level off after the recent Montes del Plata pulp mill project. These projects, though supported by the Uruguayan government, have not gone unopposed, as concerns over environmental and social effects within the country and disputes between Uruguay and its neighbor, Argentina, have played a part (Switzer 2014, Cubbage et al. 2007). Figure 3.1 shows the approximated wood producing regions

The strategy for investigations in Uruguay was to procure good quality data, analyze the current forestry situation using the data, and explore the utility of the SRTS model within the context of Uruguay. The goal is two-fold: to evaluate the state of the growing Uruguayan industrial timber market, and to demonstrate SRTS as a potentially useful tool in South America for industry players and policy makers alike.

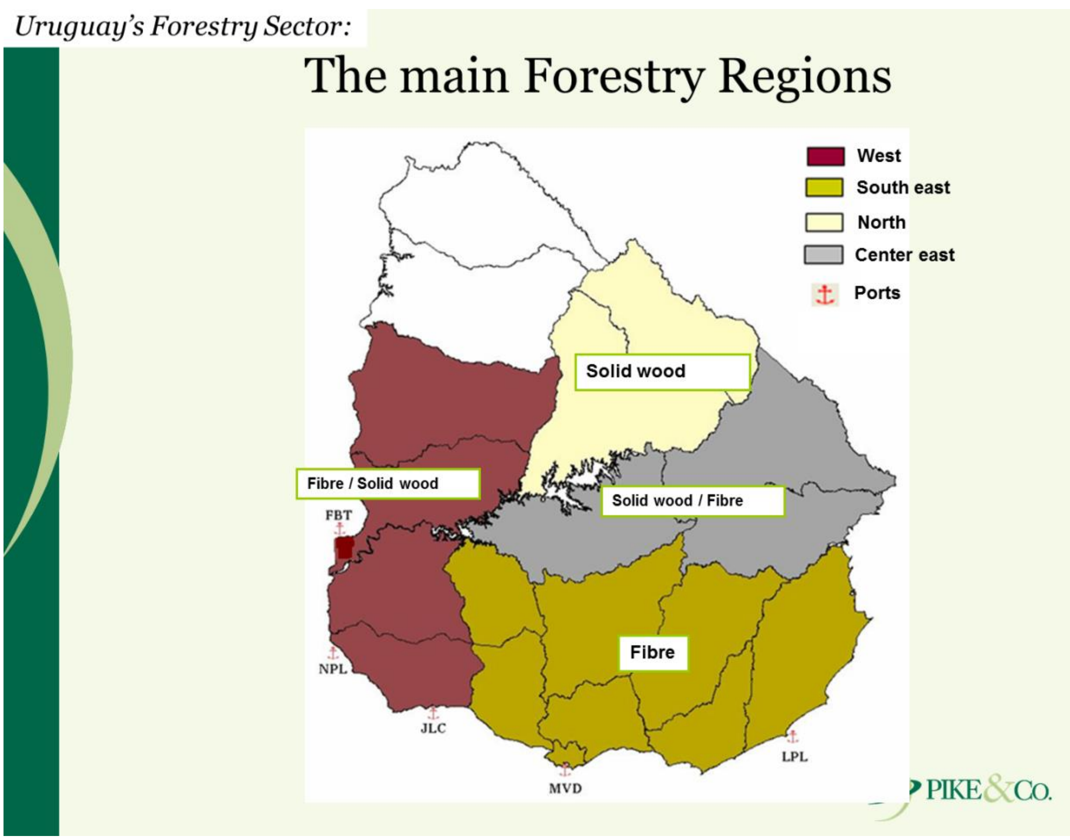

Figure 3.1. Map of Uruguay with approximate main industrial forestry regions. Source: Pike and Co. 2013.

Methods

Data requirements were met for the country of Uruguay through a cooperation with Pike and Co. (2013) based in Montevideo, Uruguay. The data provided by Pike and Co. included standing inventory by species and age class, volume by species and age class, current and projected mill demand in Uruguay, and silvicultural information. The year 2012 was used as the base year.

Volume for each species was placed into two year age classes. Age class 1 includes 0, 1 and 2 year old stands; Age class 2 includes 3 and 4 year old stands; etc. This was a deviation from standard procedure of the SRTS model in the US South, as in the South five year age classes are generally used. The change was simply the result of faster growth rates and shorter rotation lengths that necessitate a higher resolution. Figure 3.2 shows volume by age class of *Eucalyptus grandis* and Figure 3.3 shows the same for *Pinus spp.* Note that *Eucalyptus* planting has increased in the country in the last decade, while pines had a brief peak, but their area planted has dropped substantially.

Figure 3.2. Standing volume of *Eucalyptus grandis* (and similar *Eucalyptus*) in Uruguay by 2 year age class.

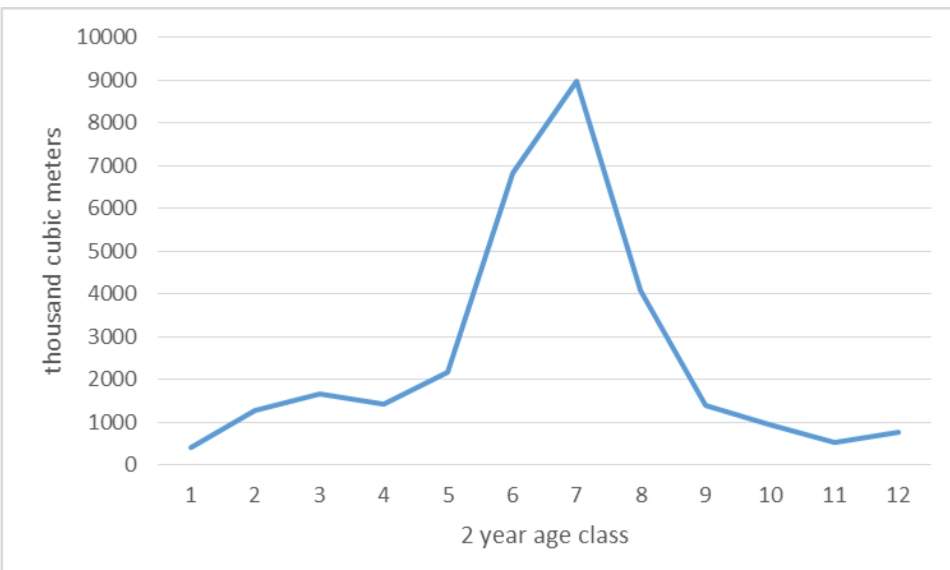

Figure 3.3. Standing volume of *Pinus spp.* in Uruguay by 2 year age class.

Current removals by age class were produced using silvicultural plantation management information. Stand ages of harvest (intermediate and final) and the amount of volume removed per unit area for each harvest were provided by Pike and Co.(Tables 3.1 and

3.2). These volumes were converted to a percent removal of accumulated volume and applied to the inventory stand table to produce current removal levels by species and age class. The SRTS model reads this management scheme as a target pattern. The biological part of the model attempts to find the volume of harvest required without deviating from the current management scheme. The program maintains, however, the ability to venture outside of the historical harvest patterns when confronted with, for example, a shortage of supply. The growth rate measurement used in the model was mean annual increment, or MAI. These average rates of growth were also provided by Pike and Co. (Table 3.3).

Demand information was also acquired for Uruguay. Current and projected mill demand was derived from the amount of fiber required by each wood user in the country. Projections were made based on planned expansions and new mill or port projects (Figure 3.4).

Table 3.1. *Eucalyptus grandis* sawtimber harvest schedule used for SRTS model.

	Age (years)	Timber Volume (m3/ha)	Pulpwood	Saw logs
First thinning	7	50	90%	10%
Second thinning	12	90	50%	50%
Third thinning	16	150	25%	70%
Clear cutting	20	360	10%	90%

Table 3.2. *Pinus spp.* sawtimber harvest schedule used for SRTS model in Uruguay.

	Age (years)	Timber Volume (m^3/ha)	Pulpwood	Saw logs
First thinning	9	25	90%	10%
Second thinning	15	70	50%	50%
Third thinning	19	90	25%	70%
Clear cutting	24	390	10%	90%

Table 3.3. Average growth rates used in the SRTS model by species in Uruguay

SPECIES	MAI (M^3/HA/YR)
PINUS SPP.	24
EUCALYPTUS GRANDIS	32

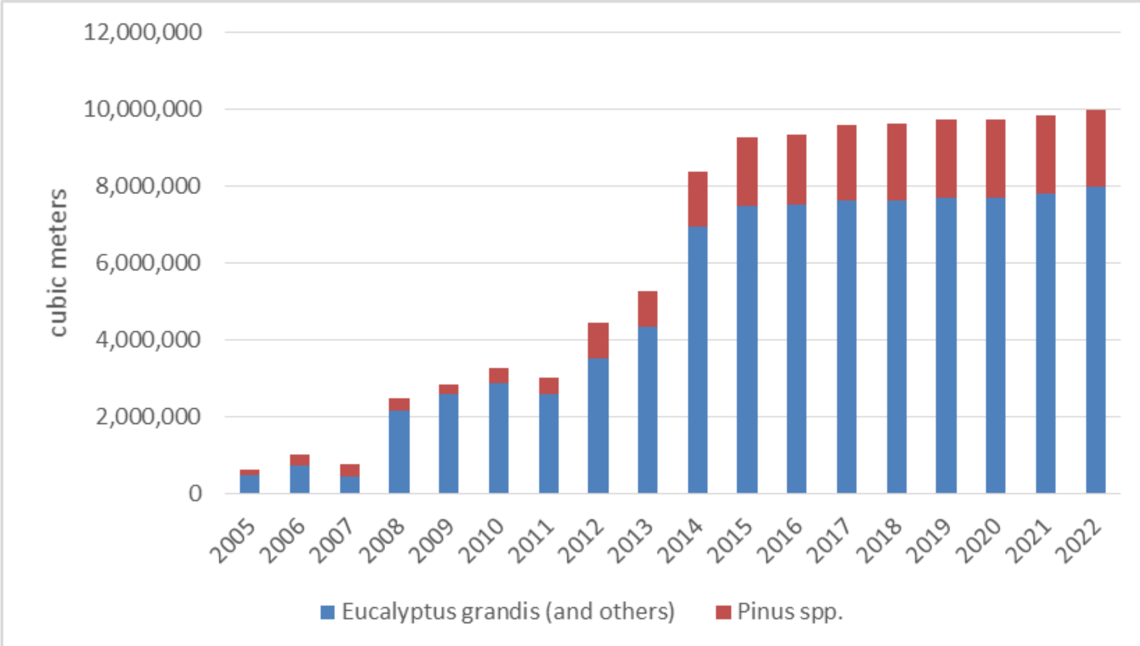

Figure 3.4. Historic and projected stumpage demand by species in Uruguay.

Demand was projected until 2022 by Pike and Co. (Figure 3.4), while the 30 year period used by SRTS ends with 2042. Preliminary runs using the harvest mode of SRTS became, essentially, a sensitivity analysis of demand paths following the ten year projection period- basically a game of finding the average rate of demand increase that would keep prices and inventory under control. Of these runs, two will be shown: one with constant demand following 2022 and one with a 5% annual increase in demand following 2022.

A much more useful analysis for the situation in Uruguay is done by using the 'Price Mode' feature of the SRTS model. This tool takes current inventory, growth rates, and removal patterns and forecasts how removal levels will need to change over the thirty year forecast period in order for price values to follow a trajectory specified by the user. 'Removals' in a market like the one in Uruguay can essentially be read as 'demand'.

The question we could then ask was an interesting one: Assuming prices will remain at or near current levels, how will demand need to react to changes in supply over a 30 year period? Stumpage demand will need to increase by how much in order to maintain price equilibrium? No additional data is required to run the price mode for SRTS. The file usually used to specify the demand scenario is simply read as a price scenario. Changes in harvest demand are usually specified by the user and are indexed by the model to be read as percent changes between years. When in price exogenous mode, the model reads the same file as percent changes to price and uses current harvest levels as initial demand.

Runs were made separately for each species, as the stumpage market in Uruguay is very species specific. Also, a sensitivity analysis was performed in order to visualize the effects of growth rate on projected stumpage demand. Growth rates used were the average growth rate used in harvest mode runs (Table 3.3), 5% increase and decrease, and 10% increase and corresponding decrease. Increases could be genetic improvement or improvement of management practices, while decreases could represent plantations not as intensively managed.

Results and Discussion

The practice of plantation forestry being relatively new to the country, the market is not a mature one. It is a growing market influenced most by top down planning rather than market reactions. Much of the new plantation establishment is based the anticipation of future demand. This is largely in contrast to the Southern U.S. market, for which the SRTS model was originally constructed.

These differences cause some problems with SRTS in Uruguay. Some of the supply and demand relationships that are normal in a developing market appear to be dire in a model that's purpose is to, for example, examine the nuances of supply shifts between regions through time in a well-established market. These "dire circumstances" can cause the model to do things like allocate harvests to age classes or products that landowners or forest products companies would not. When this happens, it can cause imbalances that show up throughout the projection period. For this reason, one take-away from our research is that the price mode is a more ideal tool for analysis of markets that are still developing and awaiting demand infrastructure to be established.

The price mode tool allows us to answer an important question for such markets e.g. how much demand is needed to keep prices constant? Evidence of problems discussed show up in the results of the initial, traditional SRTS runs for *Eucalyptus grandis* (Figures 3.5-3.8). These results are displayed as indexed price, inventory, and harvest changes through the 30 year projection period. Shown graphically, any diversion between inventory and removals cause changes in price. When demand is higher or lower than supply, price reacts.

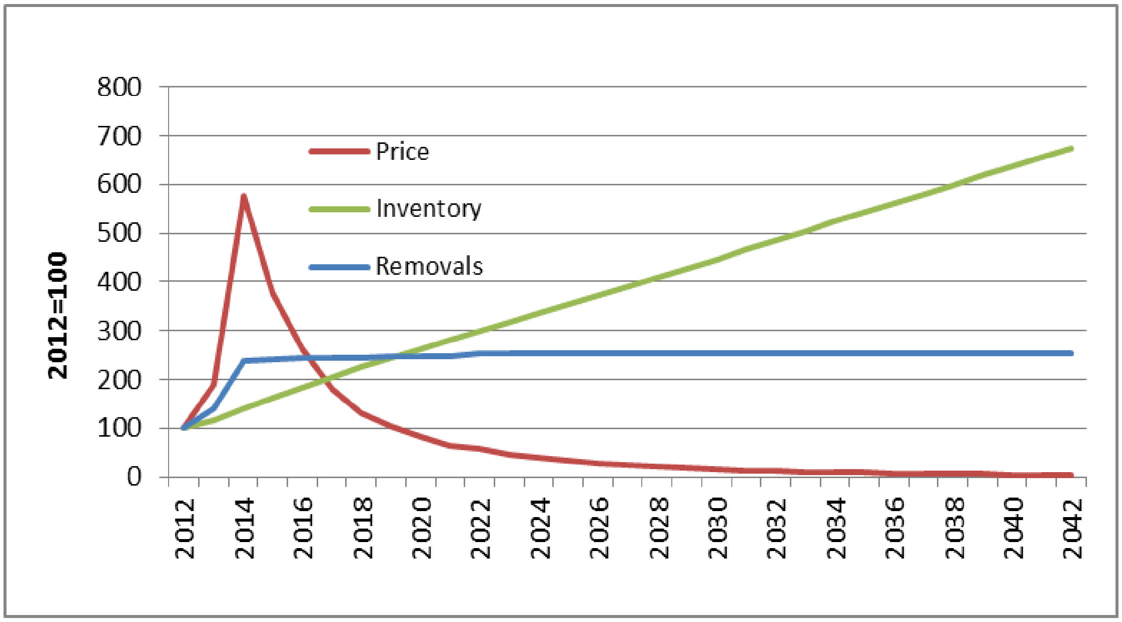

Figure 3.5. Harvest mode results for *Eucalyptus grandis* pulpwood assuming constant demand following the 10 year future demand projection.

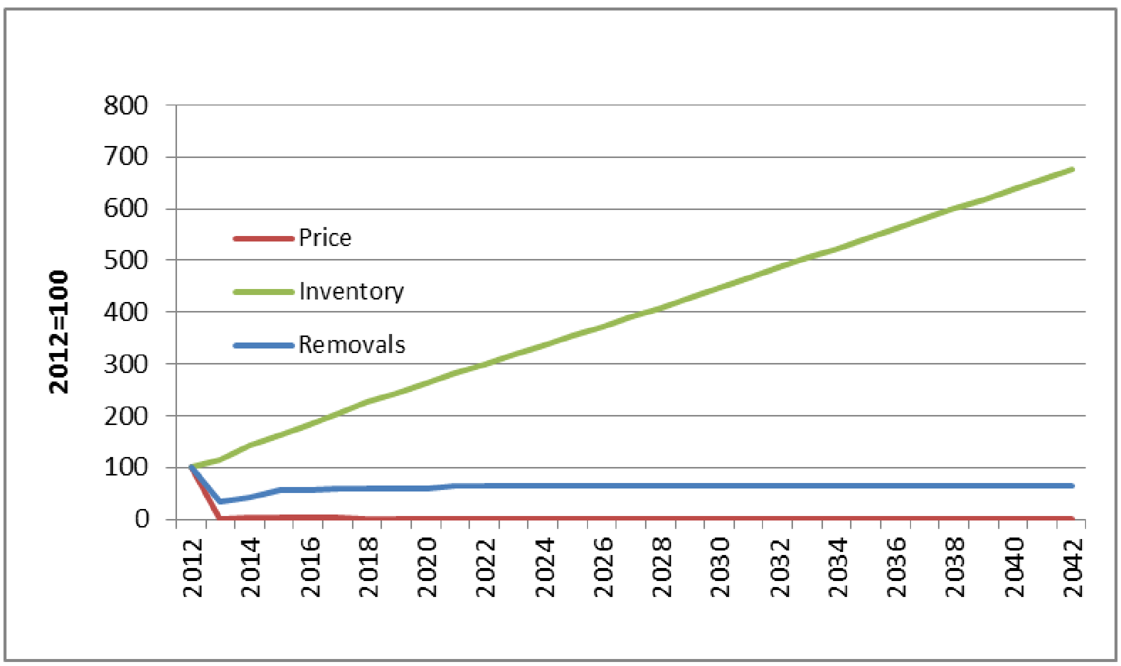

Figure 3.6. Harvest mode results for *Eucalyptus grandis* sawtimber assuming constant demand following the 10 year future demand projection.

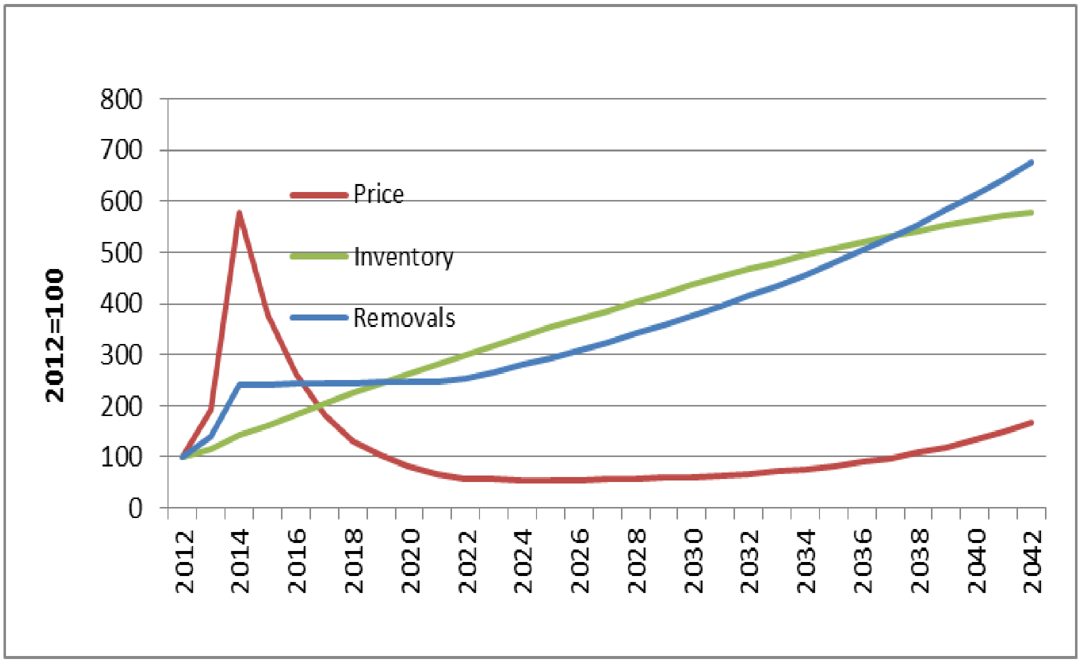

Figure 3.7. Harvest mode results for *Eucalyptus grandis* pulpwood assuming a 5% annual increase in demand follow the 10 year future demand projection.

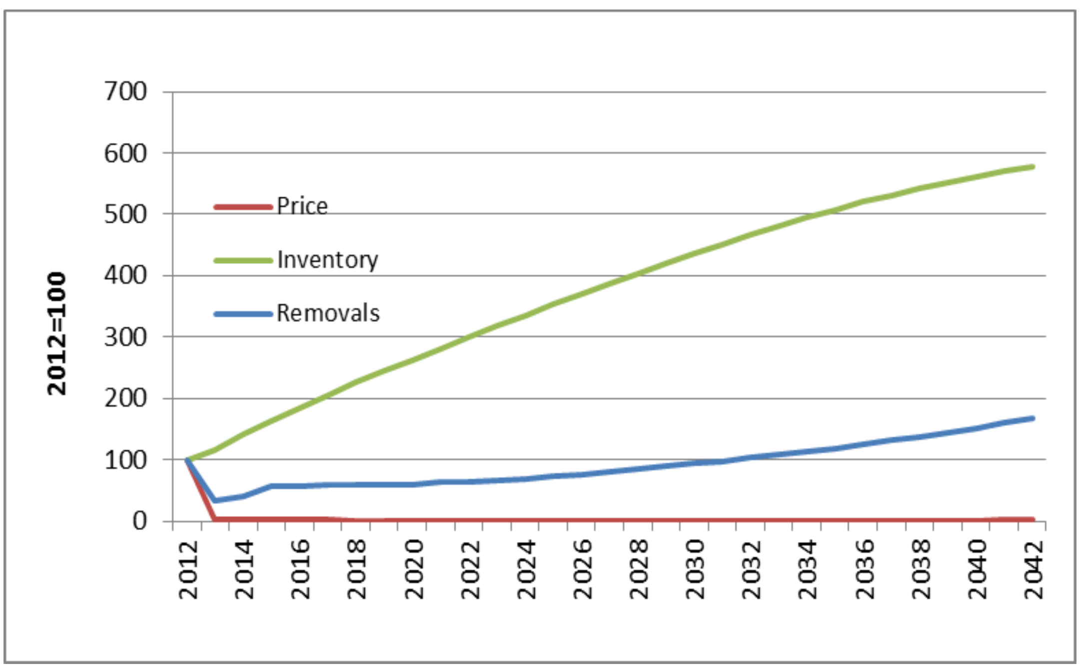

Figure 3.8. Harvest mode results for *Eucalyptus grandis* sawtimber assuming a 5% annual increase in demand following the 10 year future demand projection.

The initial harvest mode results for *Eucalyptus grandis* demonstrate the strategy that needed to be used, and why it was necessary to employ the "price mode" tool. Using a demand scenario in which demand increases by 5% each year following the initial projection period, removals finally catch up with inventory and price recover after about 30 years. The question becomes: what is the corresponding demand scenario to achieve a balanced stumpage market in Uruguay?

Examining the inventory age structure and the timing of new users entering the market, the price spike in the first few years of projection can be justified, though it may not be as dramatic as indicated by the model's results. The basic themes and questions that arise, though, appear to be valid. There very well may be a want for wood presently as new, very large users enter the market while there is a lull in the amount of mature, available volume. One reason that these trends appear exaggerated is that we asked the model to follow a specific sawtimber rotation schedule. The reality is that these harvest patterns will be adjusted according to demand and inventory. The large pulpwood and chip users are the main players in the market and many times the owners of plantations. In these vertically integrated situations it is obvious that stands will be clearcut as needed to supply the mills and ports with fiber.

The stumpage market for pine in Uruguay is problematical, although the results don't appear as dramatic as the ones for *E. grandis*. Figure 3.9 shows results for the pine sawtimber market. The model shows that there is a steady divergence of inventory and removal, and thus a somewhat linear decrease in price. Conversations with several forestry professionals in Uruguay have validated these predictions. As seen in Figure 3.3 there is essentially a wall of wood that is about to mature, but there is a lack of users for pine sawlogs. The mature pine is not something that would be of particular interest to the large pulp and chip producers. It would not take a large increase in demand to counteract what is seen in the initial results. As seen in Figure 3.10, a demand scenario that includes a 25% jump in demand about ten years into the projection period could stabilize the market and keep prices and inventory around equilibrium. It would be hard to attract investment in new sawmill facilities in the North of Uruguay where most pine plantations are located because of the concentrated volume of temporary supply in an otherwise thin market. Also, the trend in Uruguay is to replant most stands cut with Eucalyptus species planted for pulp (Perez del Castillo, personal communication, December 2013).

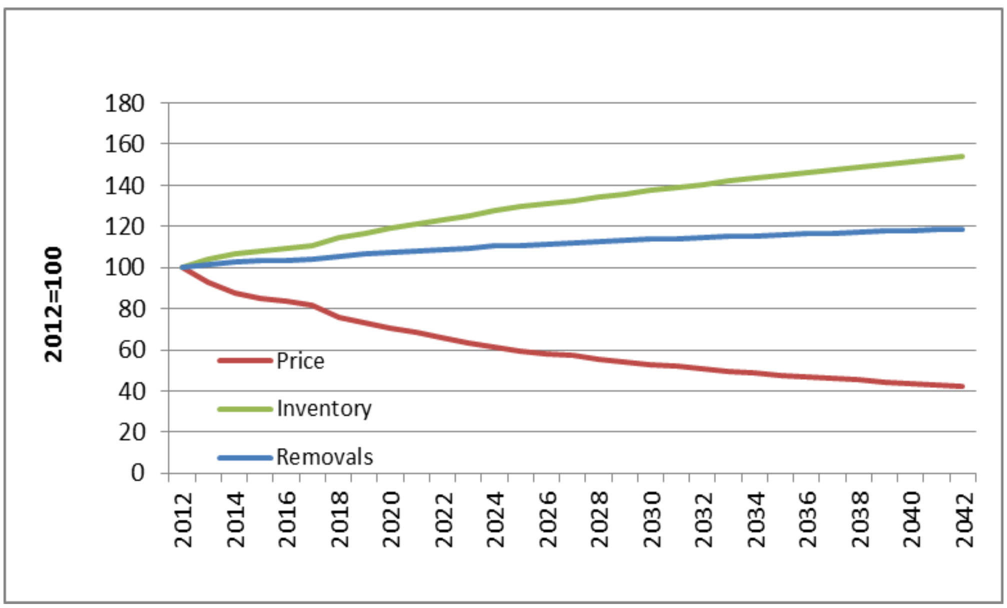

Figure 3.9. Uruguay pine sawtimber SRTS forecast.

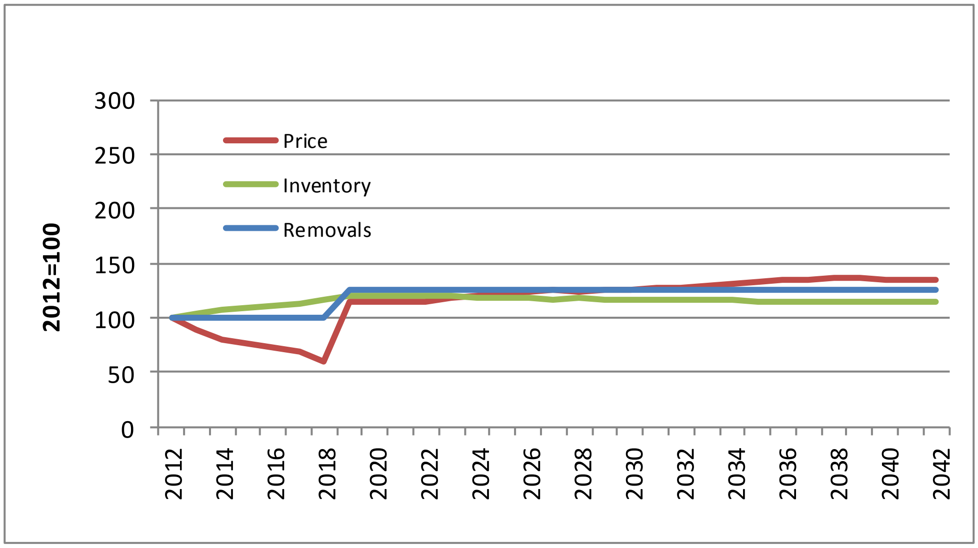

Figure 3.10. Uruguay pine sawtimber SRTS forecast with 25% demand increase in year 10.

As previously noted, the price mode tool proved to be very useful. If equilibrium prices were to be held constant, results show that *Eucalyptus grandis* demand would need to approximately double (Figure 3.11) while *Pinus spp.* demand would need to increase by about 20% (Figure 3.12) over the 30 year projection period. The results for sawtimber and pulpwood were almost equal, so results are shown by species. This can be attributed to the fact that sawtimber and pulpwood production are closely connected in the harvest patterns used for each species group. In the harvest schedule used, pulpwood is produced by thinnings of stands grown for the final product of sawlogs. It follows naturally that, when holding price constant for both sawtimber and pulpwood, the demand for each will move together.

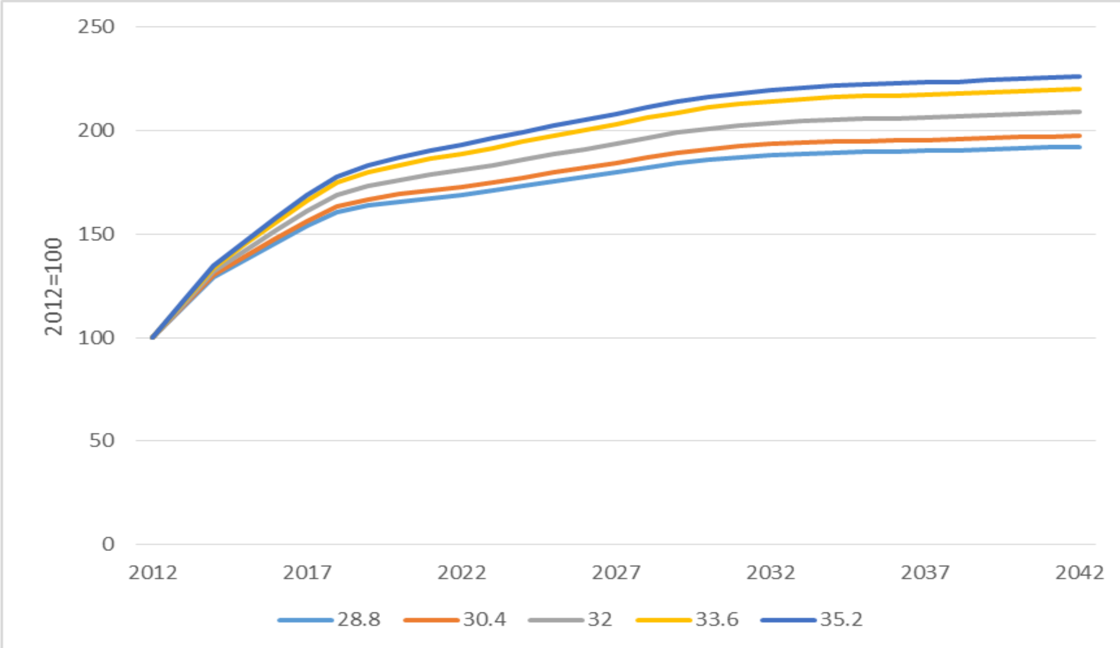

Figure 3.11. *Eucalyptus grandis* price mode results. Indexed harvest demand projection. Legend identifies MAI used in m^3/ha/yr.

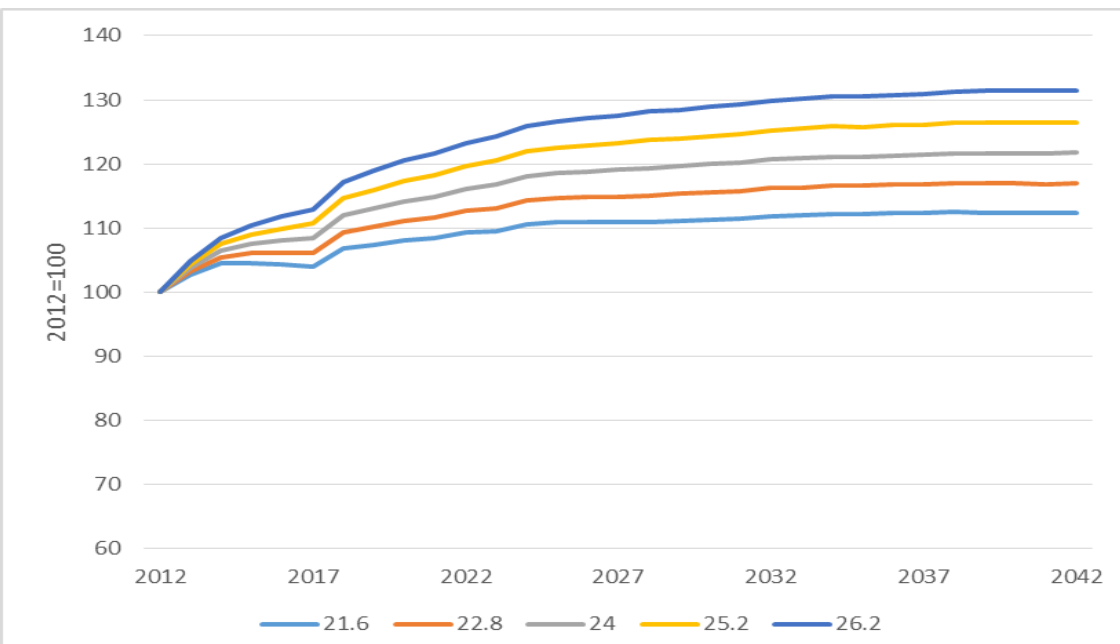

Figure 3.12. *Pinus spp*. price mode results. Indexed harvest demand projection. Legend identifies MAI used in m^3/ha/yr.

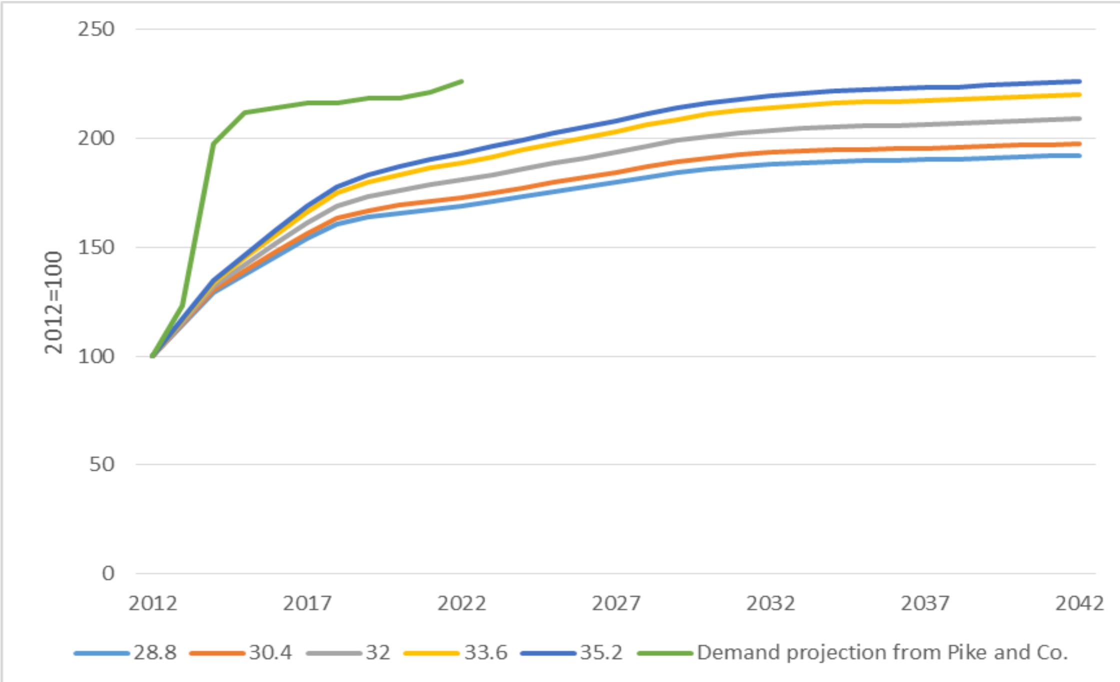

Figure 3.13. Eucalyptus grandis price mode results with Pike and Co. demand projection overlaid. Indexed harvest demand projection. MAI used in m^3/ha/yr.

Figure 3.13 shows price mode results for Eucalyptus grandis but also includes a projection of demand provided by Pike and Co. The difference between the two projections appears also to validate the initial price spike seen in previous SRTS harvest mode runs. The similarity between the two in terms of the amount of resulting demand on Eucalyptus grandis stumpage shows that planning by players in the Uruguayan market has been fairly accurate.

It is important to realize that we didn't allow expansion of planted area to play a part in the SRTS projections. In Uruguay expanding the area of plantations would require approval by the government, but it would be a reasonable assumption to say that area will expand at least a small amount during the course of 30 years. If actual demand projected by Pike and Co. appears that it will overshoot the quantity that SRTS says will be needed, remember that an expansion in planted area could fulfill that extra demand. Also, the price could simply increase in the future.

Another limitation of the SRTS model in the case of Uruguay is that it is difficult to model the area change between management styles or species during the projection period. This could be a problem in Uruguay because, for example, many of the plantations of pine sawtimber, when harvested, are being converted to Eucalyptus plantations grown for pulp or wood chips. In South America where a 30 year period can correspond to several rotation lengths, this could cause supply shifts unaccounted for by the model.

Overall, we believe that, in Uruguay, the SRTS model has proven its potential to be a valuable market analysis tool. In particular the price mode of SRTS is a useful tool for evaluating young, developing markets. The model has been, however, significantly inhibited in its power by the lack of disaggregated inventory data. For example, many *Eucalyptus grandis* plantations may be grown on a simple 10-12 year rotation for pulpwood, while others are grown on a sawtimber rotation that produces pulpwood as a byproduct. The two approaches would constitute two different management scenarios, which SRTS is designed to handle and model accurately. However, the inventory data that we have is not disaggregated by owner or management scenario. Furthermore, the volumes by age class were fairly small, so even minor changes in supply or demand could create wide fluctuations in the results. The larger the sample and forest area, of course, the less gyrations that minor changes in the inputs will cause in the results.

CHAPTER 4-

SRTS Application: Brazil

Introduction

Although Brazil has only 6.5 million hectares occupied by forest plantation (2.8 % of total planted forest globally) (ABRAF 2012), the country has an important role in the forest production economy. The high level of productivity, land availability and relative low cost make the country one of the most promising producers. The area occupied by forest plantation in Brazil increased 30% between 2005 and 2010, while China, USA and Russia increased 14%, 4% and 0.7% during the same period (Figure 4.1).

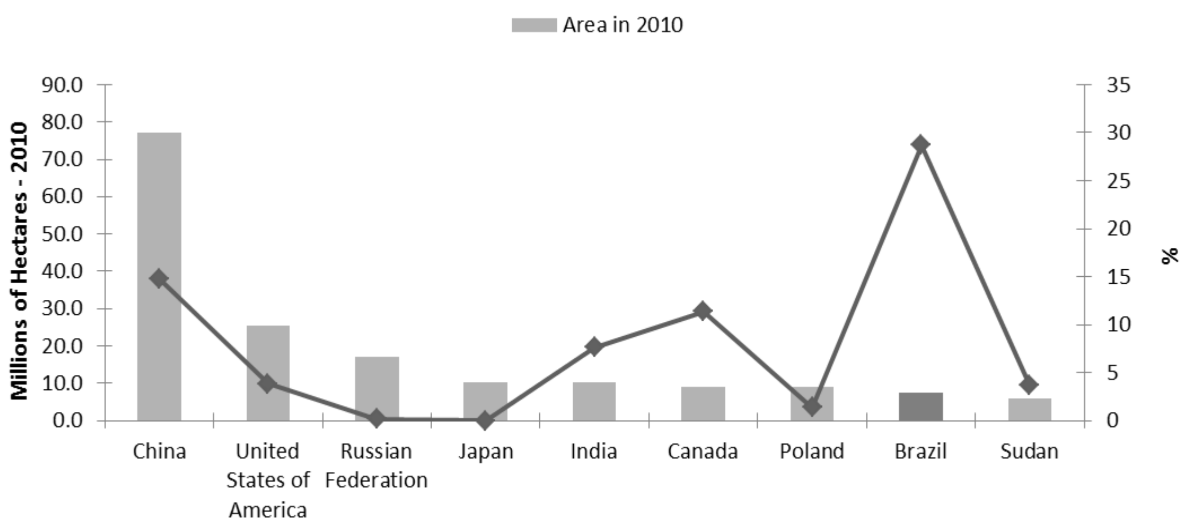

Figure 4.1 – Planted forest in the world by millions of hectares and % area increase between 2005 and 2010. Source: FAOSTAT- FAO,2010

The planted forest production in Brazil increased by 145% (47 million to 115 million cubic meters) between 1990 and 2010 according to the Brazilian Institute of Geography and Statistics (IBGE). The production demonstrates a linearly increasing trend with an annual increment of 5.5% (Figure 4.2).

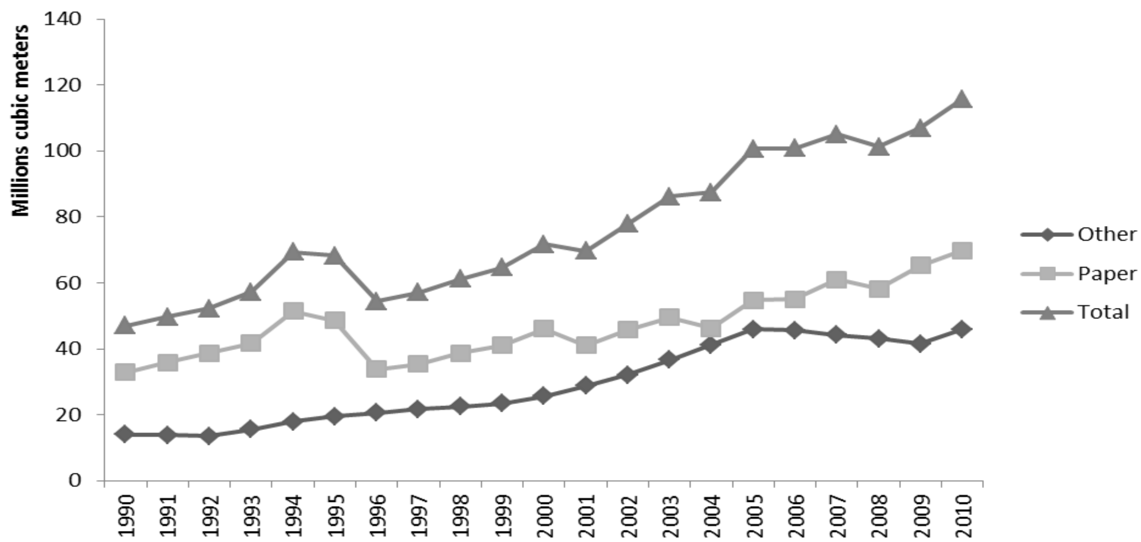

Figure 4.2 - Wood log production in Brazil. Source: SIDRA - IBGE,2010.

In 2010, wood production intended to feed pulp and paper mills was 69 million cubic meters, while the volume intended for other purposes was 45 million cubic meters. The difference in volume produced for pulp and paper is a result of investment in the sector; 10 billion dollars was invested in pulp and paper over the last 10 years as reported by BRACELPA in 2012. Furthermore, the export market has increased demand strongly in recent years, mainly from China. In 2000, 39.5% of cellulose production was exported, while in 2009 this number reached 62.9% (Montebello; Bacha 2011). The international and national demand for fuelwood has also increased in recent years. Fuelwood production has the potential to assume an important part of Brazilian production in the years to come.

The presence of pulp mills, sawmills and the demand for bioenergy made the South and Southeast regions of Brazil the most important for industrial wood production (Figure 4.3). Together, they represent 78% of the country's total production (91 million cubic meters) (IBGE, 2010).

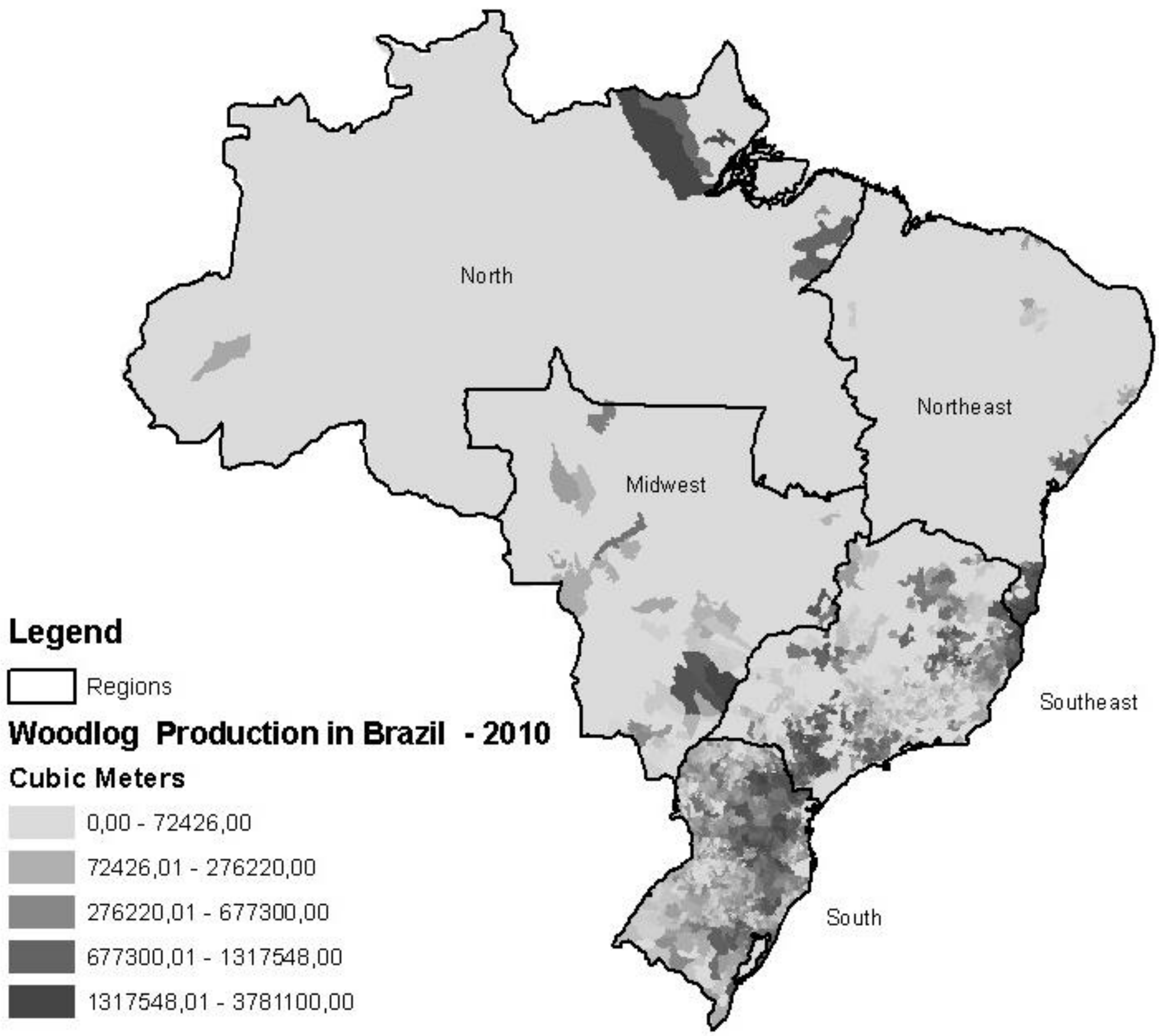

Figure 4.3 - Wood production in Brazil. Source: SIDRA - IBGE, 2010.

Brazil boasts the highest biological growth rates in the world and a strong market. On average, the growth rate is 41 cubic meters per year for Eucalyptus and 37 cubic meters per year for Pine. The trees in Brazil grow 30% faster than any other place in the world (ABRAF 2012).

The prospect for new investments in timberland are high in Brazil. Government and investors are investigating new regions and promoting establishment of new areas. Macroeconomic perspective and the internal demand for wood products have attracted investors from throughout the world. Brazil has shown particular promise as an area for growth for Timber Investment Management Organizations (TIMOs) and Real Estate Investment Trusts (REITs) (FAO 2012).

Methods

Data collection for the country of Brazil was more involved than in Uruguay. Fine-scale plantation inventory and demand data were less readily available, so a different approach was used. Inventory volume and area by species and age class were produced indirectly from public reports as published by the cooperative organization, ABRAF. Area by age class was inferred from reports of yearly area planted area, that area was expanded to represent all actors, and a mean annual increment was used to arrive at inventory volume by age class for the country of Brazil.

The ABRAF trade association (descendant of an organization called “BRACELPA”) have published the amount of hectares planted in pine and eucalyptus by members for every year since the 1960s. This area planted includes plantation that were regenerated, whether by coppice methods or by replanting. These numbers can be used, theoretically, to develop a stand table for ABRAF member plantations in the country of Brazil. If 1,000 hectares were planted in eucalyptus 5 years ago, then those 1,000 hectares are assumed to constitute the 5 year age class of eucalyptus plantation inventory (Equation 1).

(1) Area by Age Class = Ha of Planted Acres per Year * Number of Years since Planting

It should be noted that *Eucalyptus* plantation inventory was taken in the manner described above from the most recent ABRAF report, while *Pinus* plantation inventory had to be taken from various, often contradictory, statistical reports. This is because the most recent ABRAF report only provided 10 years of planting data by members of the organization. Due to short rotation lengths, 10 years was enough to develop standing inventory data for *Eucalyptus*, however *Pinus* plantations have much longer rotation lengths.

Plantation area was then expanded to include plantations established by owners unassociated with the ABRAF organization as well. The organization reports that members comprise 61.3% of eucalyptus plantation owners and 37.3% of pine plantation owners. It was assumed that non-members behaved similarly to members, and planted area was expanded using the provided factor of membership (Equation 2). Figure 4.4 shows expanded annual planting in Brazil. Another important note about the *Pinus* plantation inventory data is that a smaller fraction of the total plantation area planted in *Pinus* species is owned by ABRAF members. It is a greater assumption to say that nation-wide planting behavior can be explained by ABRAF member behavior.

(2) Estimate of Total Area Planted = Area Planted by Members ÷ Membership Fraction

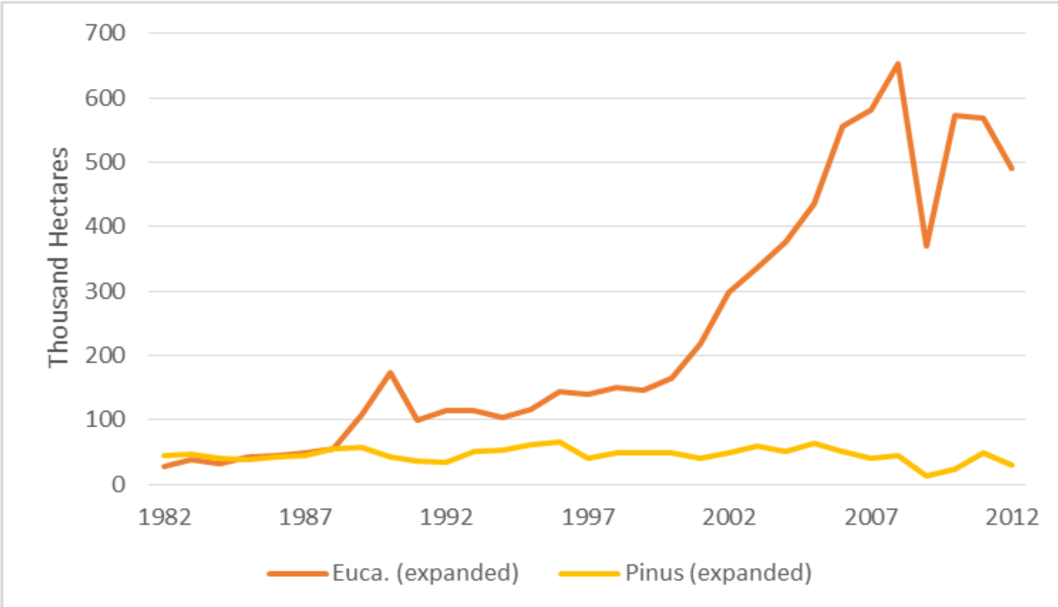

Figure 4.4. Historical annual planting of *Pinus* and *Eucalyptus* species in Brazil

After expansion of planted area to include plantations in the whole country, it was necessary to estimate total volume by age class for use in the SRTS model. Total volume was estimated by converting from area using a mean annual increment, or MAI (Equation 3). Figure 4.5 shows standing volume of *Eucalyptus* plantations, and Figure 4.6 shows standing volume of *Pinus* plantations. There is an extra drop in volume and area at harvest age of both species groups because in order to create an estimate of current volume for model input it was necessary to artificially harvest, or eliminate a portion of the volume when it would have begun to have been harvested.

(3) Total Inventory Volume by Age Class = MAI * Age of Stand * Planted Area in Ha

The MAI used were taken from the previously mentioned ABRAF report and confirmed through conversations with Brazilian forestry professionals. These rates of growth were 40 cubic meters/hectare/year for *Eucalyptus* and 35 cubic meters/hectare/year for *Pinus*.

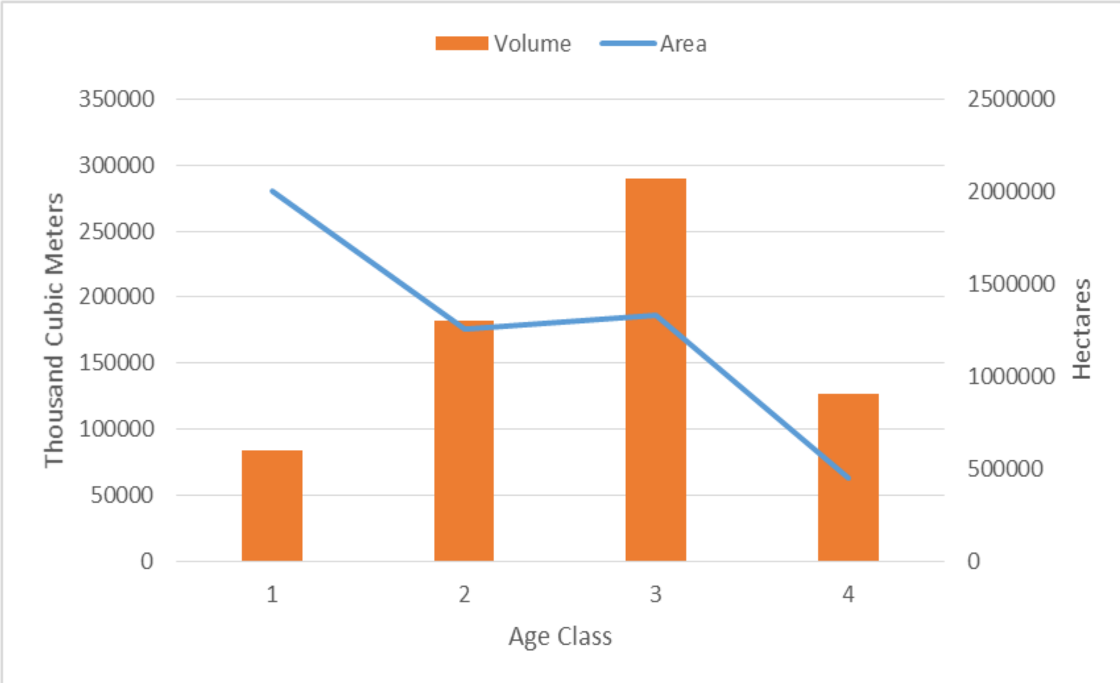

Figure 4.5. SRTS input standing area and volume of *Eucalyptus spp*. plantations in Brazil. 2 year age classes.

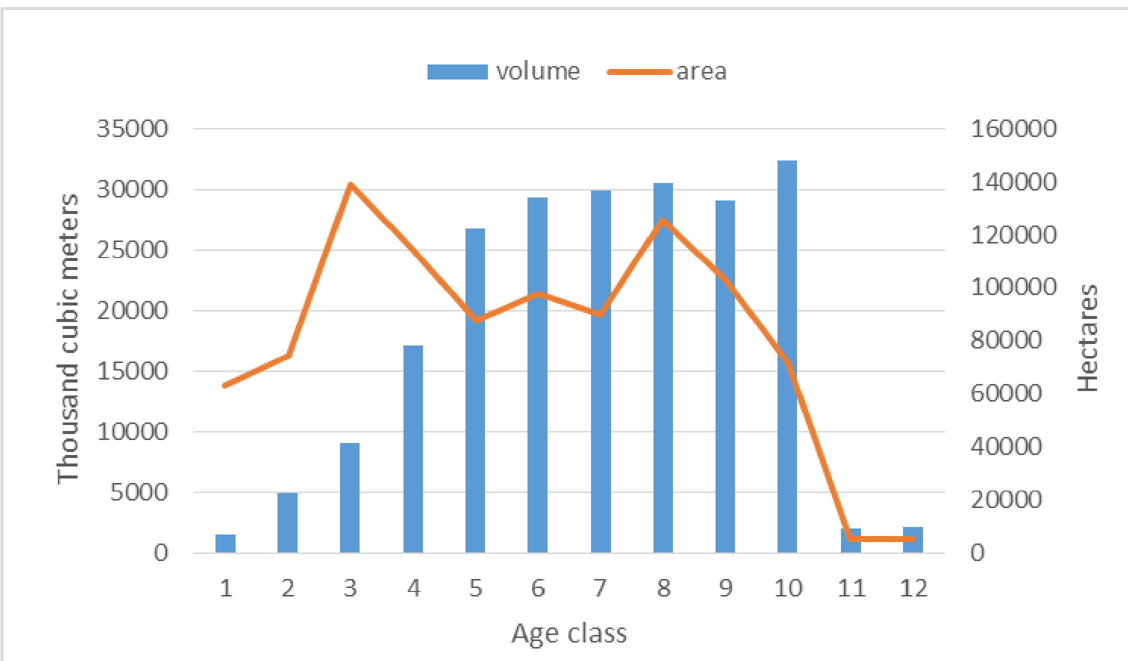

Figure 4.6. SRTS input standing area and volume of Pinus spp. plantations in Brazil. 2 year age classes

In Brazil, *Eucalyptus* species are grown for pulp on a 6 or 7 year rotation (ABRAF 2012). A conservative approach was used, and the harvest schedule that was given the model is the removal of a fraction of standing volume in age class 3 (5 and 6 year old stands) with the remainder of standing volume being removed from age class 4 (7 and 8 year old stands).

Pinus plantations in Brazil are grown on sawtimber rotations. The same sawtimber rotation was used for pine in Brazil as was used in Uruguay, however the rotation age was shortened to 20 years and the thinning ages were accordingly shortened. This was done under advisement of forestry professionals from Brazil. The harvest schedule used for *Pinus* is represented in Table 4.1.

Table 4.1. *Pinus spp.* sawtimber harvest schedule used for SRTS model in Brazil.

	Age (years)	Timber Volume (m3/ha)	Pulpwood	Saw logs
First thinning	7	50	90%	10%
Second thinning	12	90	50%	50%
Third thinning	16	150	25%	70%
Clear cutting	20	360	10%	90%

For *Eucalyptus*, a current harvest demand level acquired from a recent ABRAF report was used to establish a baseline, but future demand scenarios or assumptions were not available. One harvest mode run was made assuming that the approximate 5% linear increase in wood production (Figure 4.2) would continue for the Eucalyptus pulpwood market throughout the projection period. Another harvest mode run was made using a constant demand scenario.

For *Pinus* plantations, a current harvest demand level was not available. A current harvest level was extrapolated from the given harvest schedule and initial harvest mode runs were made, but it made much more sense to again use the price mode. This was due to the lack of data and the resulting guesses needed to produce a reliable demand scenario.

The price mode of SRTS was employed once again due to the lack of reliable demand assumptions. Instead of essentially guessing at demand scenarios, it was deemed more useful to (as with *Eucalyptus grandis* in Uruguay) allow SRTS to produce the harvest scenario required to maintain a constant price.

Results and Discussion

Initial harvest mode results for the *Eucalyptus* fiber market in Brazil were informative. The first run (Figure 4.7) used a constant demand scenario. The projection shows an explosion of inventory levels and price levels dropping dramatically by the end of the 30 year projection period. It is safe to assume that this scenario is will not be realized. As mentioned previously, the Brazilian industrial wood market is an expanding market situated in an area that is expected to continue growing in importance as a global supplier of wood products (Carle and Holmgren 2008). It is thus expected that stumpage demand will continue to increase, at least at a moderate rate.

The next step was to take the historic 5% linear increase in wood log production for the country and assume that the trend would continue for *Eucalyptus* harvest throughout the projection period. The results show that this will probably not happen, either (Figure 4.8). The SRTS model shows that such an increase in harvest levels would not be able to be sustained over the projection period. In fact it only takes ten years for disaster to strike. We did *not* program into the model an allowance for expansion in planted area, which is a limitation, but we can say that with the current land base of *Eucalyptus* plantations (a little over 5 million hectares) that a continuation of the historical linear increase in wood demand is unsustainable.

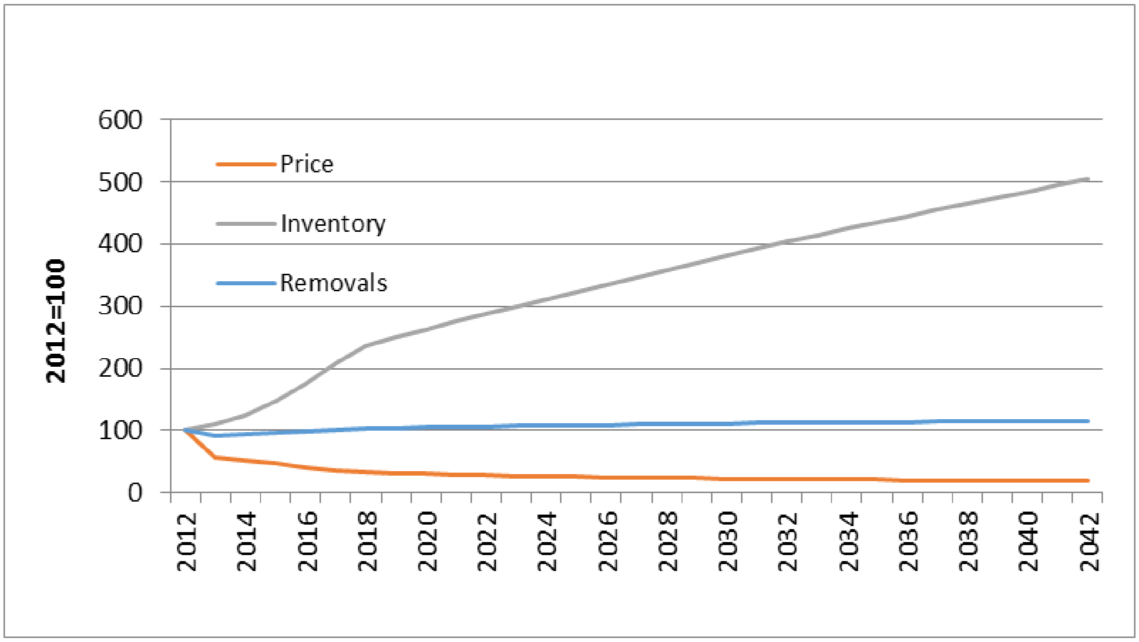

Figure 4.7. *Eucalyptus spp*. wood fiber market SRTS harvest mode projection for Brazil.

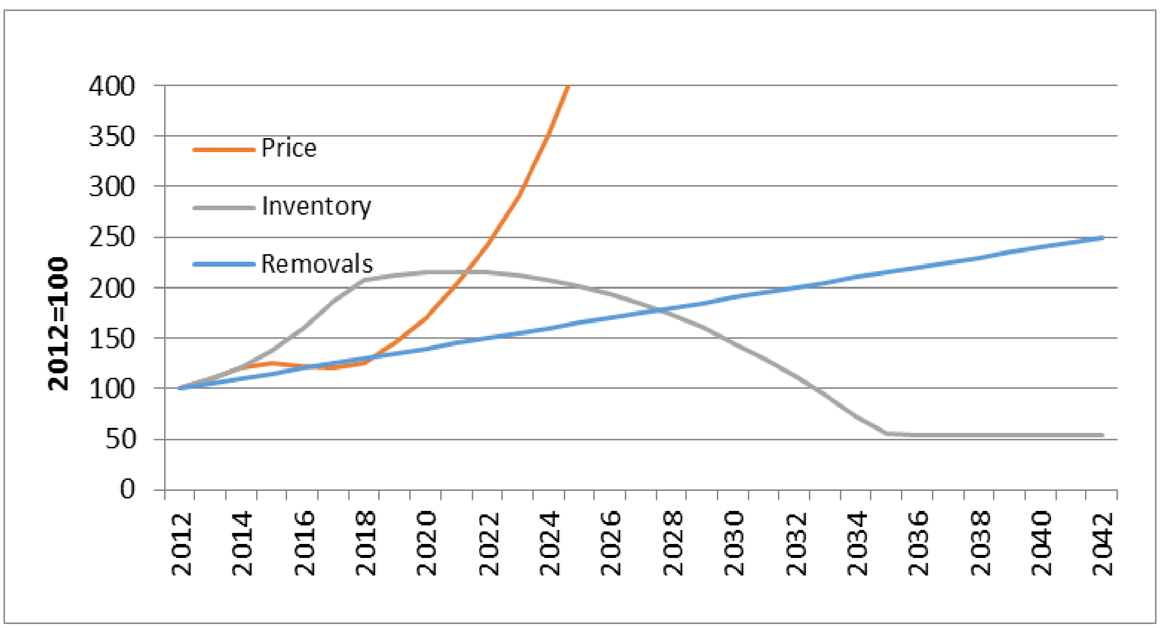

Figure 4.8. *Eucalyptus spp*. wood fiber market SRTS harvest mode projection for Brazil. 5% linear increase demand scenario.

The price mode of SRTS was used to find the equilibrium *Eucalyptus* demand path between the two harvest mode runs. Results show that Eucalyptus stumpage demand will need to increase by about 40% over the 30 year projection period in order to maintain price equilibrium (Figure 4.9). The increase was more rapid over the first 6 years and then begins to level off over the following 24 years. These results are useful and can be read as the amount of room in the market for additional users or increases in production.

This does not account for expansion in land base or an increase in productivity. It can be inferred that, if the *Eucalyptus* plantation land base were to remain constant and productivity was to remain unchanged, a demand trajectory below what is represented in Figure 4.9 would result in inventory accumulation and price decreases, while additional demand would conversely result in price increases. Given the very short rotation ages of Eucalyptus plantations in Brazil, changes in plantation extent would be realized as additional available inventory quite quickly, and this should allow for quick adjustment to any excess demand.

Figure 4.10 shows the price mode results for *Pinus* plantations in Brazil. Our results show that harvest pressure would need to decrease by about 70% to maintain equilibrium conditions. This implies a strong, current upward price pressure in the *Pinus* sawtimber market in Brazil. Again, I should note here that, while assumptions were made to produce input data for both species, the *Pinus* plantation inventory data may stand on weaker ground than *Eucalyptus* plantation data. *Pinus* plantation inventory was pieced together from various, often conflicting, statistical reports. Then, the area planted was expanded to include all landowners in the country, however only about 1/3 of *Pinus* plantation owners are ABRAF members, so the assumption that the planting behavior of this 1/3 explains the behavior of the rest may not valid. In fact, the total area of standing inventory calculated by our methods is about 1.1 million hectares, but ABRAF reports a total *Pinus* plantation area of about 1.5 million hectares. The values were not inflated to reflect the ABRAF reported value, partly because the indexed values read by SRTS would be identical. However, if the discrepancy indicates an error in the proportion of inventory held in each age class, the difference would be important. In addition to these assumptions, the price exogenous mode of SRTS assumes a current equilibrium condition in the market, essentially "doubling down" on all previous assumptions made.

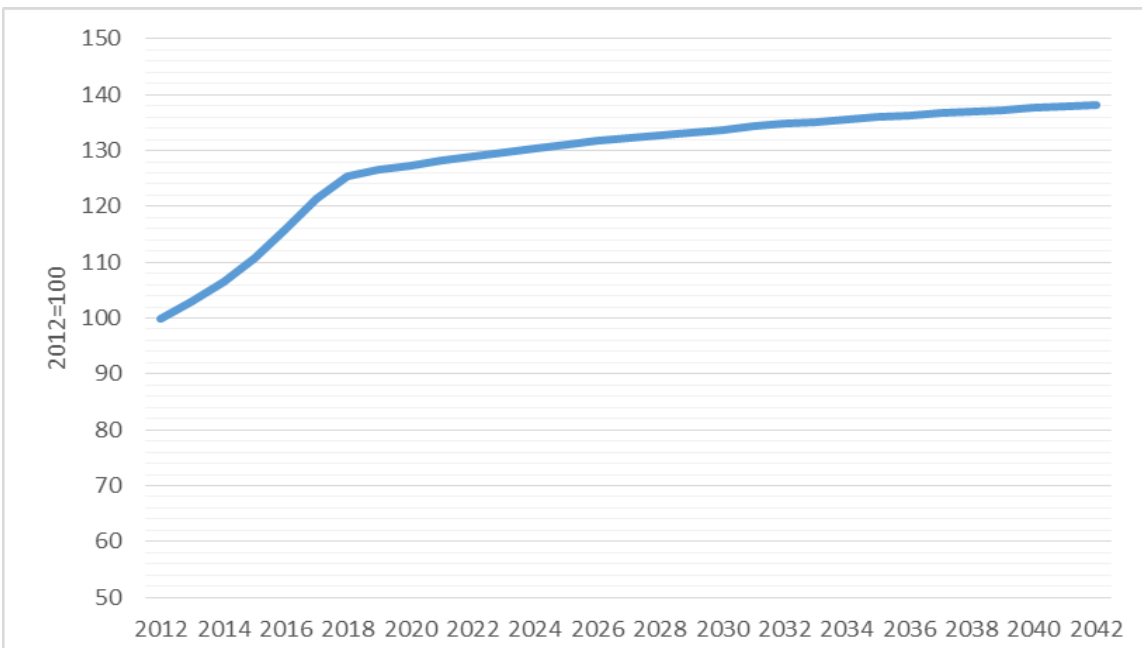

Figure 4.9. Price mode SRTS results for *Eucalyptus spp*. fiber market in Brazil. Indexed projection of removals given equilibrium conditions.

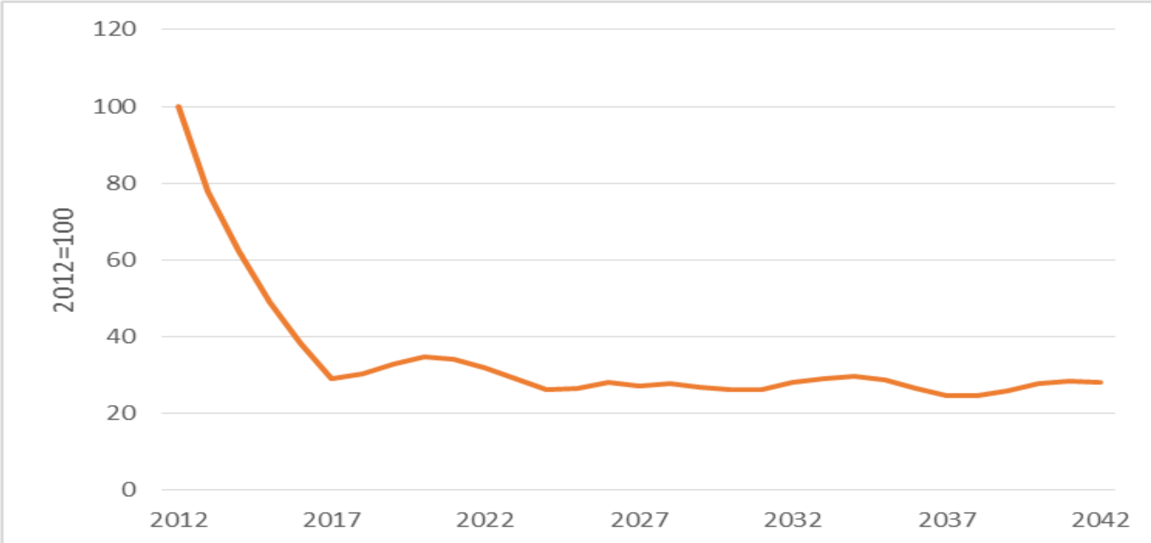

Figure 4.10. Price mode SRTS results for Pinus spp. sawtimber in Brazil. Indexed projection of removals assuming equilibrium conditions.

As in Uruguay, the SRTS model in Brazil has been shown to be a useful analysis tool for markets in South America, however its capabilities are limited by the amount and quality of data available. This however, is the model's principal limitation, and the predictive ability and relevance of the model will only improve as better data sets become available. Specifically, regionally disaggregated inventory and demand data would be of great utility. Given regional data, the SRTS model could be used, as in the US South, to model shifts in supply between regions and the geographically heterogeneous effects of certain policies.

SRTS could be very useful in Brazil because of growing investment interest, but also because of the special global interest in Amazonia. It appears that Brazil will continue to grow its influence in the global industrial wood market, mainly with its fast growing *Eucalyptus* plantations. The speed at which it does so will depend on the rate of expansion of the forest plantation land base. This may depend on the comparatively growing demand for beef globally, the extent to which plantations and cattle farmers can cooperate through silvopastoral systems, and Brazil's willingness to convert more natural and previously unexploited lands.

CHAPTER 5-

Summary and Conclusions

The goals of SOFAC to develop a South America timber supply model, and eventually a partial equilibrium model of trade within the Americas, were introduced. The goal of this thesis was to acquire the data possible and employ the SRTS model to examine several South American markets. A hypothesis was that the SRTS model could provide a useful tool for analysis in South America in the absence of regional, empirical market analyses in the literature.

The literature was reviewed for the major partial equilibrium timber sector supply modeling approaches in order to give context to the development and use of the SRTS model. The SRTS model is one of the only models in use that empirically optimizes timber supply for multiple products, species, owners, and management types at the subregional level and then explicitly aggregates results to the regional and national level. This is an essential capability when modeling important industrial producing regions with significant investment interest and enterprise. One can imagine that, in a country like Brazil, industrially produced wood from forest plantations that have replaced sections of the Amazon are looked upon differently than plantations in the Southeast of the Country, but all of the global, long-run optimization models in use would view both the same. There should be policy interest in developing a timber supply model that can investigate supply shifts between subregions.

The SRTS model framework is used in the country of Uruguay to investigate the state of the markets for *Eucalyptus grandis* and *Pinus spp.* The price exogenous analysis that we were able to do was a useful one, particularly in Uruguay. In a developing market where the establishment of supply is more centrally planned, an estimate of harvest demand needed to keep a balanced market is quite useful, and intuitive. *Eucalyptus grandis* demand was projected to double within 30 years, while *Pinus* demand was projected to increase by 20% if current price levels are to hold constant. The results appear consistent with information received from colleagues in Uruguay. These projections assume a static amount of area planted. The assumptions built into this type of analysis, such as starting equilibrium conditions and fixed plantation area, are somewhat limiting.

The same methods were applied to the country of Brazil. Inventory data was extrapolated from publicly available reports and used to assess *Eucalyptus* pulp and *Pinus* sawtimber markets on a nationwide basis. A historic 5% linear increase in demand for *Eucalyptus* industrial roundwood was deemed not to be sustainable based on harvest exogenous mode SRTS runs. The demand trajectory projected to hold 2012 price levels allows for an approximate 25% increase in the first 6-8 years with an approximate 10% gradual increase in the following 20-22 years. This assumes static land use. If 2012 prices are to be held for *Pinus* sawtimber, harvest demand levels would to decrease by about 70%. While constant plantation extent is a reasonable assumption for *Pinus* plantations in Brazil, the results are taken cautiously. Many assumptions were made and there is evidence that the inventory data extrapolated from various reports may not reflect the situation in reality.

We were able to perform some interesting analyses for a few markets in Brazil and Uruguay using the SRTS framework. We were not utilizing, however, the full capabilities of the model due to limited data extent and specificity. The strength of the SRTS model is in its empirically strong, data rich approach to capturing to dynamics of timber supply and its subregional interplay. This would be an extremely useful capability to bring to the important timber producing regions of South America, but with the data available right now a more theoretical and less data-intensive approach may be more successful at creating a continent wide analysis. The SRTS model framework has proved flexible, however, and can provide the tools for whatever type of analysis the data permits. And with SRTS, as the amount and quality of data available increases, so too will the scope and power of the model in South America.

A motivating hypothesis behind this project was that the development of joint SRTS Southern U.S. and South America models will provide better projections of timber supply in both regions than the existing global models. It is not completely clear whether or not we are able to answer this question at this point. Certainly, simply separating out a country like Uruguay with a detailed analysis is a step forward, however we remain quite a distance from providing a joint characterization of both the Southern U.S. and South America. So, with given data constraints, the SRTS data is simply not able to provide any comparable larger scale analysis linking the two regions. This still remains a general motivating question of this line of research, and will be a focal point of further investigations moving forward.

The second original hypothesis was that the collection and use of detailed, fine scale data on timber area, inventory, growth, and removals in the SRTS framework will lead to better projections of timber supply in both separate regions of the Americas. For the U.S. South the SRTS model does provide the best option for projecting timber supply when the goal is to analyze the southern market at the sub-regional level. This makes the model the preferred tool for businesses, investors, and certain region-specific policy analyses in the U.S. South. It is important to be able to analyze such a significant wood producing region in fine detail with an empirically valid model. We do believe that the SRTS framework will be able to extend this capability to South America, however with current data limitations we were not able to achieve a comparable analysis.

The SRTS model framework allowed for useful examination of several timber markets individually, however the scope of was very limited and in some cases many assumptions had to be made in order to achieve the results that were achieved. At this point, the type of analysis that can be right now does not provide a comparable product to SRTS U.S., and neither does it provide a competing product to the global models in use. This does not change the fact that a void exists for a timber supply modeling framework useful at the managerial and regional policy making levels in South America, and we see the potential for SRTS to fill this need. A possible next step would be the compilation of sub-regional data sets in the country of Brazil. Other hypotheses regarded the potential for SRTS to provide a useful new management tool for companies, investors, and policy makers; and that South America would continue to increase in importance as an industrial wood producing region.

We believe that the SRTS framework has indeed been proven to provide a useful decision making tool. A strong asset of the SRTS modeling framework is its flexibility. Even hampered by data limitations, we were able to perform very useful and intuitive analyses. The model is able to do the best it can with what it is given. The scope and strength of the SRTS model projections increases along with the scope and strength of the data available.

If the markets we were able to analyze are to be taken as representative, we believe the South American region will continue to grow in importance in the global wood products market. As it does so, we see the region continuing to become increasingly specialized in fast growing eucalyptus species. These are the markets in which our analysis shows continued growth in supply and infrastructure. The South American region will most likely continue to grow in global importance as a specialized producer of fast growing fiber and biomass products.

Once again, future directions in this line of research with be to continue the pursuit of relationships, cooperation, and the compilation of detailed data sets for South America at the sub-regional level. As this process moves forward our modeling efforts in the region will bear increasingly more fruit as the full capability of the SRTS modeling approach will be realized.

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APPENDICES

Appendix A

Area planted by age class and species group in Uruguay

	Species Group: Area (ha)	
Age Class	*Euc grandis, dunii*	*Pinus taeda,* other pine
0	6,285	1,066
1	25,319	6,402
2	36,791	9,630
3	51,599	10,677
4	61,916	12,770
5	57,578	6,394
6	32,367	12,172
7	17,106	4,865
8	9,876	6,847
9	6,941	5,622
10	7,196	8,705
11	8,376	14,134
12	9,359	22,954
13	9,764	23,860
14	14,730	18,347
15	9,403	11,108
16	7,106	5,605
17	7,230	3,289
18	6,971	1,861
19	5,321	1,490
20	3,926	320
21	615	579
22	854	977
23	425	4
24	463	129
25	49	92
26	75	63
27	35	6
28		249
29	26	202
30+	152	877
Total	397,855	191,297

Appendix B

Plantation volume by age class and species group in Uruguay

Age Class	Species Group: Inventory Volume (000 m3) WO Bark	
	Euc grandis, dunii, otros	Pinus taeda, other pine
1	591,692	97,082
2	1,805,600	292,353
3	3,751,069	489,928
4	6,141,217	781,392
5	6,997,845	498,875
6	4,701,976	1,155,609
7	2,887,277	540,641
8	1,926,317	874,542
9	1,609,860	801,874
10	1,826,686	1,357,386
11	2,421,179	2,463,721
12	2,675,264	4,369,153
13	3,110,043	4,905,956
14	5,315,554	4,085,117
15	3,742,337	2,645,483
16	3,058,845	1,422,365
17	3,271,812	873,396
18	3,248,497	520,029
19	2,701,643	436,172
20	2,116,985	99,578
21	330,476	191,659
22	378,638	341,855
23	254,920	1,280
24	279,297	49,099
25	30,813	36,460
26	57,765	25,706
27	24,639	2,218
28		110,614
29	22,572	92,221
30+	113,657	445,762
Total	65,394,469	30,007,524

Appendix C

Plantation area by species and age class in Brazil (thousand hectares).
'Members' refers to ABRAF member companies.

Year of Planting	*Euca.* (expanded)	*Euca.* (members)	*Pinus* (expanded)	*Pinus* (members)
2012	489.6	300.1	29.5	11.0
2011	568.7	348.6	49.6	18.5
2010	573.2	351.4	22.3	8.3
2009	369.3	226.4	13.7	5.1
2008	653.8	400.8	43.7	16.3
2007	581.2	356.3	40.8	15.2
2006	557.1	341.5	51.7	19.3
2005	436.2	267.4	62.7	23.4
2004	375.9	230.4	50.4	18.8
2003	336.2	206.1	58.7	21.9
2002	298.2	182.8	49.3	18.4
2001	218.5	134.0	39.2	14.6
2000	165.0	101.1	48.4	18.1
1999	145.0	88.9	49.0	18.3
1998	150.4	92.2	49.3	18.4
1997	140.5	86.1	40.8	15.2
1996	143.6	88.0	64.7	24.1
1995	116.3	71.3	60.8	22.7
1994	104.5	64.1	52.4	19.6
1993	114.3	70.0	50.5	18.8
1992	113.5	69.6	34.6	12.9
1991	98.5	60.4	36.9	13.8
1990	174.0	106.7	42.6	15.9
1989	107.8	66.1	56.6	21.1
1988	55.5	34.0	55.7	20.8
1987	48.6	29.8	44.4	16.6
1986	44.6	27.4	41.9	15.6
1985	42.6	26.1	38.8	14.5
1984	31.3	19.2	39.2	14.6
1983	38.1	23.3	46.9	17.5
1982	27.7	17.0	45.3	16.9