The Colombian Forest Sector Model – An analysis of forest plantation policy in Colombia

by

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Abstract

An economic model for the Colombian forest sector (Colombian Forest Sector Model – CFSM) is developed and used to analyse Colombia´s forest plantation policy covering the 2018 – 2038 horizon (PFCm policy). The CFSM is a structural partial equilibrium econometric model that forecasts quantities and prices for the Colombian forest product markets using the neoclassical theory of competitive markets. Phase I of the CFSM (CFSM-I), developed in detail in this dissertation, includes a simulator of growth and yield for the Colombian forest plantation and two market (sub)models: the Unprocessed Wood (sub)model, and the Manufactured Wood Products (sub)model. Using the CFSM-I, two PFCm policy goals were simulated to unveil their impacts on the Colombian forest sector. Simulations of an expansion of Colombia's forest plantation current area (0.3 million ha, Mha, on Dec 2015) to 1.5 Mha by 2025 indicate that Colombia would increase the 2015-2047 volume available of industrial wood in plantations by 5 times (annually 20.8 million cubic meters of underbark roundwood (Mm^3rsc)). In monetary values, this expansion would importantly impact the unprocessed wood market. Supply and exports of wood would multiply by 2.5 and 14.5 times in the next 25 years meanwhile its price of supply would drop by 24%, respectively, and on average, compared to the scenario of no expansion of the current plantations.

Simulations of a 2023-2038 5.5-times expansion of the current (2022) production capacity of Colombia’s manufactured wood forest products industry show that on average in the next 25 years and compared to the no expansion scenario, consumption of unprocessed wood and manufactured wood products of the pulp & paper industry would increase by 8% each, and the imports of the latter and of manufactured products of the furniture industry would decrease by 35% and 25%, respectively. Alternative policies of plantation area expansion (0.45 Mha, 0.765 Mha, and 2.0 Mha under sustainable rotation, and 0.3 Mha harvested without replanting) also simulated enrich the set of information for policy-makers and other stakeholders in preparation for the first round of the PFCm policy evaluation, scheduled for 2023 after the completion of its first implementation period in December 2022.

Acknowledgments

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Chapter 1
Introduction

Academic literature has long been recording the use of forest sector models (FSMs) in forest policy analysis. Defined as large-scale partial equilibrium models of the forest sector that represent natural, technological, and economic facts together with their interactions that enable the determination of product prices and supply and demand quantities (Rivière & Caurla 2021), FSMs were first used in forest policy deliberations in USA in the 1980s (Adams & Haynes 2007a).

Latta et al (2013) report the Timber Assessment Market Model TAMM by Adams & Haynes (1980), a model for the US solid wood market, as one of the first completed FSM developed and used as a tool for policy analysis, by supporting the study of present (1980) and anticipated uses of renewable resources, by means of an economic framework required by the US Forest and Rangeland Renewable Resources Planning Act in 1980. TAMM opened the door for more FSMs to evolve in North America and elsewhere (Haynes 1993, Adams & Haynes 2007, Rivière & Caurla 2021). By 2020, at least 30 FSMs had been developed and used for forest policy analysis.

Although the evolution and applications of the FSMs are reported in a global, regional, and national context, the application of the latter is almost entirely concentrated in countries in North America and Europe. For countries in the tropical world, information on FSMs and their use for forest policy analysis is rather scarce. This issue was already reported at the beginning of the 1990s by Haynes (1993) after attending a satellite meeting of the 10th Forestry World Congress (1991), which focused on the methods used for forest sector analysis and their applications in developed and developing countries.

Haynes observed a disparity of forest sector analysis and planning methods, tools, and applications among countries in North America and Europe, and those in the developing world. While the developed countries saw a substantial progress in "analysing and managing their forest resources", the latter "had neither benefitted from the analytical advances nor advanced very far in understanding their forest sectors" and, very rarely had forest sector analysis, conducted before 1991, included a model application. One prominent example of what Haynes asserts is Colombia, a tropical country endowed with rich forest resources, but with high rates of deforestation and difficulties in supplying from its national sources the forest products demanded. Currently, this country is redesigning its forest policy and implementing, with the help of the international community, several forest initiatives to boost the forest sector. However, there are no complete tools, such as a FSM, available to the stakeholders involved in these processes, for analysing the impact of these initiatives on the forest sector.

In his publication, "Forest Sector Analysis for Developing countries. Issues and Methods" (1993), perhaps the only paper discussing in depth the use of FSM in the tropical world, Haynes considers the lack of data as the most serious impediment in building and applying FSMs in developing countries. He mentions World Bank and FAO data sources as helpful, but warns of their lack of concern with statistics needed for FSMs, such as prices and quantities of forest products traded in the context of the local markets of a country. For prices, Haynes argues that in many countries of the tropical world, the only data collected is that from international trade or from some wholesalers, and this data might not reflect transactions to the final consumers as desirable for FSMs.

Although Hayne's appreciation for forest data might have been true for some specific cases, he completely overlooked the richness of, perhaps, the oldest and most important source of organized data for the forest sector that most tropical countries could have used (and can currently utilize) for building a FSM: the National Accounts. He also did not mention the National Accounts for framing FSMs.

Indeed, the use of National Accounts as frame and source of data for building FSMs is rarely reported in the literature. The Canadian Forest Product Sector Model (CFPSM) developed by Kant et al. (1996) is a unique and the only reported example in how one can use the national accounts framework for giving theoretical structure to FSMs, using macro and microeconomic foundations and, at the same time, as an important source of data for building this type of models. However, the CFPSM is not a FSM, as it only includes the manufactured wood forest products, and nor is it a model developed and applied in policy analysis for a tropical country.

This research addresses the issues mentioned above. Using the case study of Colombia, this thesis shows how to develop from the scratch a complete model for the forest sector of a tropical country, and use it to address policy-relevant questions for providing useful knowledge for policy, and decision makers and other stakeholders.

More specifically, the research objectives of this research are as follows:

1. Develop the Colombian Forest Sector Model (CFSM)

2. Evaluate the target set by the Forest Development National Plan (FDNP) of the expansion of commercial forest plantation for wood production area by 1.5 million hectares- Mha, by analysing the implications that this policy will have on the Colombian forest sector.

3. Evaluate the impact that an expected increase in the number of manufacturing plants (a positive shock on the supply of manufactured wood forest products) will have on the performance of two important macroeconomic factors: domestic consumption and imports.

4. Compare the forecasted results derived from the simulation of the model with the FDNP goal to five additional scenarios of alternative forest plantation area: 0.3 Mha, 0.45 Mha, 0.765 Mha and 2.0 Mha under sustainable rotation, and 0.3 Mha harvested without replanting, in order to provide a more complete view of the impact of such policies on the forest sector.

The research involved theoretical, methodological, and empirical work. Results of this research are presented and discussed in this thesis in seven additional chapters. These chapters provide a road map for new researchers on how to build a FSM model for a tropical country from scratch, with information from National Accounts, and use it for policy analysis, and the details of the FSM and policy analysis for Colombia. A brief overview of these chapters is as follows:

Chapter 2: Literature Review and Background, summarizes the relevant literature on the evolution of forest sector models, the use of general equilibrium models for the forest sector, policy applications using forest sector models and key information of Colombia's forest sector and its forest policy.

Chapter 3: Structure and Specification of the Colombian Forest Sector Model - CFSM (Theoretical Approach, Conceptual Mapping and Formulation), which includes the theoretical framework of the model, a description of the stages of this research (Phase I and II), including the ones outside of the scope of this thesis, as well as all the theoretical equations utilized for Phase I of the CFSM (CFSM-I), with a variable list and their description, and the economic justification necessary for the selection of each variable.

Chapter 4: Calibration for Phase I of the CFSM (CFSM-I) - Data consolidation, is devoted to data collection, transformation, and consolidation. It shows where to find the data needed to estimate the model once its theoretical structure has been defined, how to catalogue it to avoid lack of transparency of the model, the usual issues of sectoral data of National Accounts and other sources, how to overcome these issues, and what is the typical work (data transformation) to obtain the consolidated data for equation estimation. The chapter presents a sector-specific database for the forest sector in Colombia, which did not exist before. The appendix 4-1 includes the database as a virtual library and its guide for accessing the documents and data, the latter covering mostly the period 1970-2018. The appendices 4-2 and 4-3 present several novel research by-products, resulting of the work done to obtain the consolidated data and its analysis, named consolidated sectoral products. They are important contributions to improve the Colombian forest statistics and sectoral knowledge and to exemplify how to get familiar with the target to be modelled, the suitability of the theoretical framework selected for modelling, and the richness of National Accounts for analytical modelling of the forest sector in the tropical world.

Chapter 5: Calibration - Estimation, Validation, and Software Application for the CFSM-I, presents the estimated equations of CFSM-I with the statistical output for various tests performed to confirm the validity of the estimations, and the elasticities for key variables of the forest sector derived from the estimation of the model. The estimation was done based on consolidated data mostly of the supply and use tables of the National Accounts of Colombia for the period 1975-2015. The appendices 5-1 to 5-3 include all the documented work for estimation and validation, and also the details of the software application for running the CFSM-I.

Chapter 6: Colombian Forest Plantation Growth and Yield Simulator (SCRPFC) and Estimations of volume of wood in forest plantations before the annual harvest (VAS) for 2015-2047, is presented in a paper format. It presents the 2015-2047 estimation of VAS for six scenarios of forest-plantation-area-expansion policy goals calculated by using the SCRPFC simulator developed as one of the components of the CFSM-I. The SCRPFC is able to forecast the volume of wood available for supply VAS (needed to compute the volume of wood available for supply after the annual harvest (VAST), one of the policy variables of the model), for a time period of 100 years for 21 species in several site index sites in Colombia. Details of the structure, validation, and the software application of the SCRPFC, and other aspects of its use for obtaining the results discussed in this chapter are presented in appendices 6-1 to 6-6. Chapter 6 ends with the policy implications of these alternative goals for the forest sector as per objectives 2 and 4 of this research.

Chapter 7: Impact estimation of the 2018- 2038 Commercial Forest Plantation Value Chain Policy (PFCm policy) using the CFSM-I includes the results of running the CFSM-I to obtain analytical inputs, in monetary values, for analysing the economic implications on supply, consumption, exports and imports and their corresponding prices of a full implementation of two goals of the PFCm policy as per objectives 2, 3 and 4 of this research: the 1.5 Mha of expansion in commercial forest plantation areas, and the further development of the manufactured wood forest products industry. It also includes the comparison of those results to the ones obtained for simulating the CFSM-I under alternative policy options of forest plantations expansion mentioned in objective 4.

Finally, chapter 8 presents the conclusions drawn from the research and discusses the potential subjects for future research. This chapter also includes a discussion of the limitations of the research and general recommendations for policy makers.

Some parts (Chapter 6) of this thesis have been published in a refereed journal – Forest Policy and Economics, and therefore this chapter is presented as a standalone refereed paper. The remaining chapters are presented and organized more like a traditional thesis. The combination of two formats have resulted in some repetition of the text in Chapter 6 from other chapters.

Chapter 2
Literature Review and Background

2.1 Concepts of Forest Sector and Forest Sector Model

A key aspect of developing a model is to clearly understand both the target it represents and the approach to be used in modelling this target. For the specific case of this research, these correspond to the concepts of forest sector and forest sector model, respectively.

The forest sector is understood by different authors as the integration of several activities related to forests. Haynes (1993) reports the term "forest sector" as being firstly used by Panders et al (1978) in the description of their model of Scandinavian forestry, and by forest sector he considers "all aspects of forestry from the basic land tenure issues, to harvesting, production and consumption decisions" (Haynes 1993, p. 1). Rivière & Caurla (2021) review different approaches to define the forest sector and argues that for Solberg the forest sector comprises "both forestry and forest industries and the interactions between these two activities (Solberg 1986, p. 420)." They also cite the definition of the forest sector provided by Buongiorno (2014, p. 291) consisting of "all the activities related to the growing and harvesting of wood in forests, to the transportation and transformation of this wood in forest industries and to the utilization of the resulting products in downstream activities" to claim that division between upstream and downstream segments, corresponding to forestry and industries, respectively, is common. They finally conclude that the forest sector is "large and complex, due to comprising structures and processes integrated both horizontally and vertically (Johnston and Van Kooten, 2014), but also of different natures: biological dynamics, economic behaviours, industrial processes, etc."

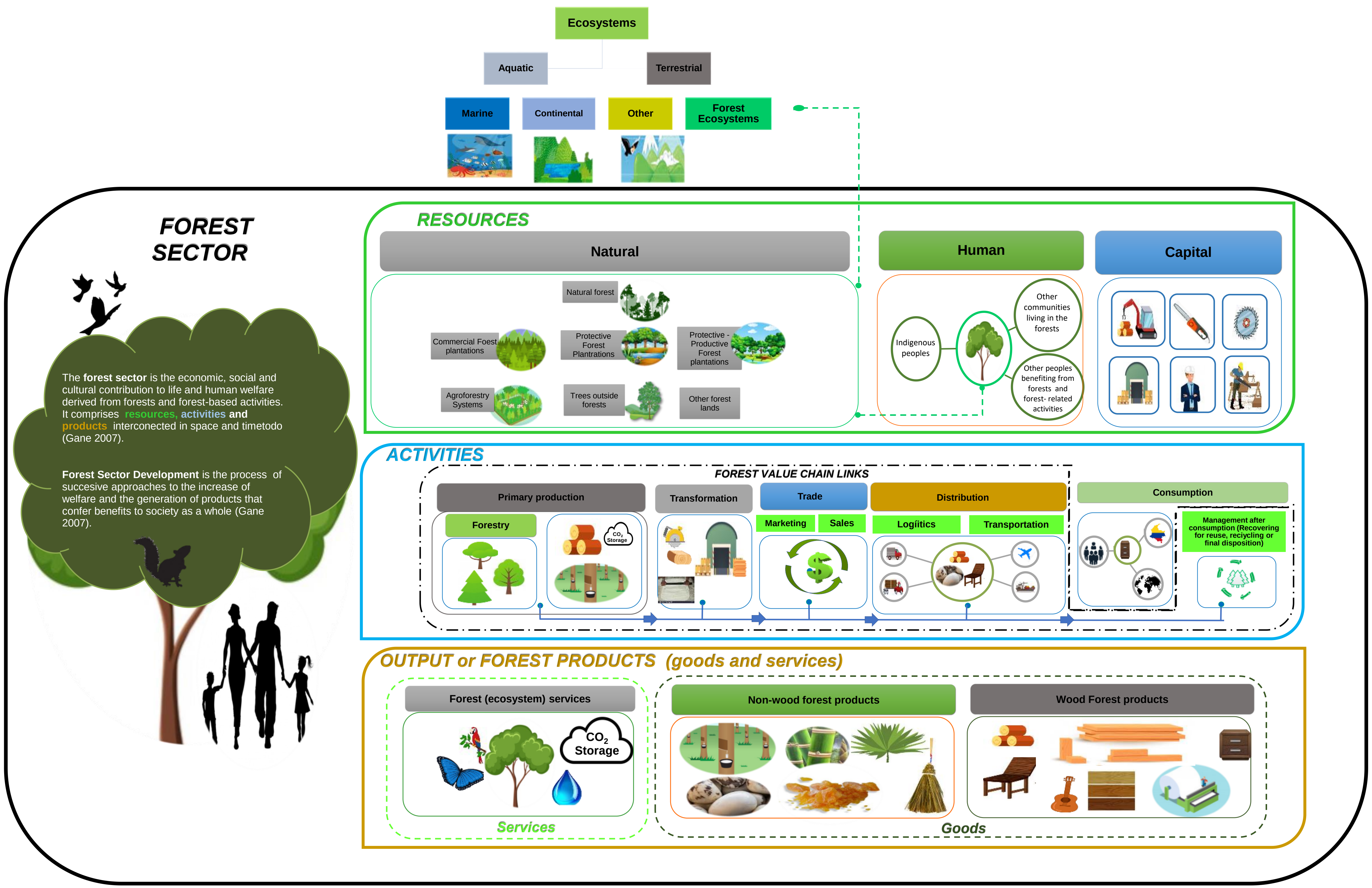
However, none of those concepts is a holistic and complete definition of the forest sector. For example, Buongiorno's definitions is very restricted as it refers only to one type of products of the forest sector, the wood products leaving the non-wood forest products and ecosystem services out. Solbers' and Hayne's definition of the forest sector could qualify as a less restricted concept than Buongiorno's, but unfortunately these authors do not provide details on what is included into forestry and forest industries. Those definition might be concentrated also in the wood forest products specially for Solberg's as usually forest industries are only related to the manufactured wood products. Finally, conclusion of Rivière & Caurla is more a set of characteristic of the forest sector than a definition of it.

For this research, the concept of the forest sector follows the holistic approach of Gane (2007, p. 32) who defines it in broad terms as “the economic, social and cultural contribution to life and human welfare derived from forests and forest-based activities”, encompassing “three components: resources, activities and outputs” which are interconnected in space and time. Figure 2-1 presents a visual representation of the target to be modelled under this research.

In regard to what is a forest sector model (FSM), academic literature includes various types of models under this tag, showing an evolution of the FSM concept to be more specific with the passing of time. Solberg (1986, p. 420) coined the first definition of FSM as a “model (numerical or strictly analytical) which takes into account both forestry and forest industries and the interaction between these two activities.” However, this definition was not rapidly accepted as shown by the diverse examples of what is a FSM provided by Haynes (1993) in his extensive study on forest sector modelling before 1991 which includes: a) the descriptive models (e.g. those commanded by FAO), the gap models (e.g. the outlook studies for the forest and forest products sector in Europe collectively known as the European timber trends studies -ETTS- developed by UNECE & the FAO European Forestry Commission), the models based on system-dynamics principles (e.g. the Scandinavian forest sector model developed by Panders and others in 1978), resources models (e.g. the Timber Supply Model-TSM) and the market models (e.g. the spatial and non-spatial partial equilibrium models developed and applied in North America[1]) which fit very well Solberg’s definition of a FSM. Haynes also mentions the multisectoral Input-Ouput and General Equilibrium models, including the forest sector separately, as viable alternative to FSMs but not as an example of what is a FSM. Later on, in the book “Resources and Market Projections for forest policy development, twenty-five years of experience with the US RPA Timber Assessment”, the editors Adams & Haynes (2007) consider only spatial and non-spatial partial equilibrium models as examples of FSM though they do not give a formal definition of a FSM. The most recent definition of a FSM is provided by Rivière & Caurla (2021), for whom a FSM is

[1] In a non-spatial (market) equilibrium model only one country or region is considered; in a spatial (market) equilibrium model several spatially isolated markets compete among themselves (Haynes 1993).

Figure 2-1 Forest sector concept



a large-scale partial equilibrium model of the forest sector that represent natural, technological, and economic facts and their interactions enabling the determination of product prices and supply and demand quantities. This research follows closely the concept of FSM by Rivière & Caurla.

2.2 Evolution of the Forest Sector Models (FSMs)

The use of FSMs has a long tradition (Kallio, Moiseyev, & Solberg 2006). The first complete FSM was developed by W.L.M. Mckillop (Buongiorno 1996) around mid-1960s[2]. McKillop (1967) developed a partial equilibrium econometric model to explain price formation and consumption levels of the US forest stumpage and timber products (lumber, paper, paperboard, plywood, and roundwood). The model specification consisted of linear supply and demand equations built with time-series data.

Following Mckillop´s work, other FSMs were built in the US before the mid-1970s. The timber market model in Douglas fir regions by Adams D.M. (1974), the econometric model of softwood lumber and stumpage markets by Robinson V.L. (1974), and the dynamic, spatial equilibrium model for softwood timber by Haynes R.W (1975), are cited by Boungiorno (1996) as relevant examples of that time. The work of Mckillop, Adams, Robinson, and Haynes, among others, set the theoretical approach and some of the methods for developing the partial equilibrium models of the forest sector which, later on, became known as FSMs[3].

The FSMs were the answer for forest scientists trying to incorporate the rapid changes in commodity prices, prevalent in 1970, into policy analysis (Adams & Haynes 2007; Haynes 1993). The Timber Assessment Market Model-TAMM (Adams & Haynes, 1980) was perhaps the most

[2] In 1950 the USDA Forest Services started developing formal planning frameworks for the forest sector using the approach known as gap analysis (or gap model), which was used until mid-1970s. Under this model, forest issues were considered in the context of the gap between the trend of the demand for forest products (converted to roundwood) and the estimated supply of timber (Haynes, 1993). Although gap models can be considered as the first forest sector models (Haynes, 1993), they do not fit well in the definition of forest sector model by Solber (1986) and Rivière & Caurla (2021).

[3] A partial equilibrium model of the forest sector can be defined as an economic-theory-consistent mathematical representation of the forest market (industry/sector), independent from the other markets (industry/sectors) in an economic system.

known one, widely used for policy analysis, and the first of the equilibrium models built for US forest markets. TAMM uses a spatial equilibrium algorithm to provide long-term projections of prices and quantities of consumption and production in stumpage markets. It also provides effect simulations of alternative policies and programs for several regional markets - 9 in US and 3 in Canada (Adams & Haynes 1996; Adams & Haynes 1980; Haynes 1993).

Because TAMM was concentrated in the solid wood sector, a model dealing with the US pulp and paper industry was developed. This model was named PAPYRUS (Gilless & Buongiorno 1987), which became the North American pulp and paper model NAPAP (Buongiorno 1996). Like TAMM, PAPYRUS is also a spatial partial equilibrium model. It provides long-term projections of production, consumption, imports, exports, equilibrium prices, and fiber inputs for 14 commodities[4] for the US pulp and paper industry. It considers 11 supply and nine demand regions in the US and Canada, and three net demand regions to capture the rest of the world (Gilless & Buongiorno 1987).

A global FSM was designed during the 1980s by a group of scientists at the International Institute for Applied System Analysis –IIASA. It was named the IIASA Forest Sector Model or Global Trade Model - GTM. This spatial partial equilibrium model included 16 intermediate and final forest products obtained and/or traded over 18 global regions; each region comprised an all-final-products demand model, a forest industrial production model, and a timber supply model, with every region connected by bilateral trade linkages, recognizing transportation costs, tariffs and non-tariffs trade barriers and trade inertia due to logistical, marketing or trade policy considerations (Kallio, Dykstra & Binkley 1987). Later on, the GTM evolved into the CINTRAFOR GTM, at the University of Washington, and it was expanded to include projections of production, consumption, prices, and trade for 10 forest products in 43 producing regions and 33 consuming regions, with over 400 trade flow links for supply and demand among these regions (Buongiorno, Zhu, Zhang, Turner, & Tomberlin 2003, Turner & Buongiorno 2003, Haynes 1993).

By the end of the 1990's two more global forest sector models had been developed: The Global Forest Products Model-GFPM (Zhang, Buongiorno, & Zhu 1997) and the Timber Supply Model-

[4] Softwood and hardwood round wood and residues, mechanical, semi-chemical, and chemical pulp, newsprint, paper, and paperboard, and four recycled commodities.

TSM (Sedjo & Lyon 1996). The GFPM was a partial equilibrium model developed at the University of Wisconsin using a similar structure and programming as PAPYRUS; it considers timber supply, processing industries, product demand and trade of the forest sector to project future prices and quantities for 14 commodities and 180 countries under several scenarios (Buongiorno et al. 2003, Turner & Buongiorno 2003). The TSM was first delivered in 1990 and then updated in 1996 (TSM96). The TSM96 uses an economic market supply and demand to project inter-temporal prices and quantities for forest products in eight global regions. In this model, supply is described in detail and considered endogenous to the model, while demand is exogenous and determined in far less detail than in most of the models mentioned above (Buongiorno et al. 2003, Sedjo & Lyon 1996).

More forest sector models were developed in the 1990s and during the 2000-2013 timeframe. In a paper called "A review of recent developments and applications of partial equilibrium models of the forest sector" (Latta et al. 2013), the authors account for those models developed in and for Europe and USA during the above-mentioned period. In the paper, the models are grouped in recursive dynamic and inter-temporal optimization models, with all of them having either a direct connection to those explained above, or indirect links trough the methodology pioneered by them (Latta et al. 2013).

Among the dynamic models not depicted above are: the Finish Sector Forest Model SF-GTM (Ronnila 1995), the Norwegian Trade Model NTM (Trømborg and Solberg 1995), the US South sub-regional timber supply model STSM (Abt, Cubbage, & Pacheco 2000), the European Forest Institute Global Trade Model EFI-GTM (A. M. I. Kallio, Moiseyev, & Solberg 2004), the NTM II (Folsland Bolkesjø, Trømborg, & Solberg 2006), the French forest sector model FFSM (Caurla, Delacote, Lecocq, & Barkaoui 2009; Caurla, Lecocq, Delacote, & Barkaoui 2010) and the United States Forest Product Module USFPM of the GTM (Ince, Kramp, Skog, Spelter, & Wear 2011). The inter-temporal optimization models are: The forest and agriculture optimization model FASOM (Adams, Alig, Callaway, McCarl, & Winnett 1996), the US Pacific Northwestern Regional Models PNW-RM (Schillinger, Adams, Latta, & Van Nalts 2003), the Norwegian forest sector model Nor-For (Sjølie, Latta, Gobakken, & Solberg 2011), and the European Forest and Agriculture Sector Optimization Model EUFASOM (Lauri, Kallio, & Schneider 2012; Schneider et al. 2008).

Between 2013 and 2020 other FSM were also developed. Rivière & Caurla (2021) recount the Alberta FSM (2014), the global REPA-PFC Forest Trade Model RPFTM (2014), the Nordic FSM (2016) and the latest version of the French forest sector model FFSM++ (2016).

For all forest sector models mentioned above, three are inactive (TAMM, PAPYRUS, IIASA GTM) and one active although heavily modified (TSM); these are credited with building the groundwork for the current forest sector models (Latta et al. 2013, Rivière & Caurla 2021).

2.3 Forest Sector Models and Forest Policy Analysis

FSMs have proved to be useful tools for explaining and foreseeing the development of the forest sector, including policy analysis and market forecasts (Latta et al. 2013, Sjølie et al. 2015). Policy analysis, as defined by (Dunn 1981), is "an applied social science discipline which uses multiple methods of inquiry and arguments to produce and transform policy-relevant information that may be utilized in political settings to resolve policy problems." Its goal is to illustrate the "contentious dimensions of policy questions, to explain the intractability of policy debates, to identify the defects of supporting arguments, and to elucidate the political implications of contending prescriptions" (Hawkesworth 1988). In this light, forest policy analysis and its goals are the subset of policy analysis that is applicable to the forest sector; it is in this context that FSMs have long been used in several countries around the world.

One of the most significant cases traditionally used to illustrate the use of integrated market and resources models for the forest sector (FSMs as defined in the preceding sections), for exploring policy issues and examining the effects of alternative policy actions in the forest sector, is that of the United States. Adams & Haynes (2007a) report the use of FSMs (into what is known as The Timber Assessment Projection System-TAPS) in the forest policy deliberations since 1980. They state that "information and projections made with these models have come to play a significant role in the development of land management strategies and forest policies at both national and regional levels."

Before 1980, GAP models in the US were used to provide an analytical framework for the public perception that demand for forest products would exceed the available supply. Assumptions that the demand and supply volumes of the forest markets could be projected independent of each other, and that the changes in future prices would follow a similar path as in past trends, were at the heart of policy analysis reports before the 1980s. In this context, policy actions were needed to reduce or eliminate the gap of a shortfall of, for example, 0.08 billion cubic meters projected for 2000 (Adams & Haynes 2007a). As reported by the same authors, the introduction of FSMs (which were based on supply-demand balance approach) into the TAPS during the 1980s allowed policy discussions of forest sectors to finally address the role of prices, as well as the rate of price changes, related to the concerns of the rapid inflation in the late 1970s and early 1980s. By being able to obtain price behavior forecasts under different policy scenarios, policy analysis gained a more proactive role, as it could then shift its focus towards forecasting the impact each projected price change would have on the market (the social acceptability component). If a projected price increase was socially unacceptable, policy could focus, for example, on private land management reforms, as forest sector model simulations were showing that a hypothetical program intensifying management on private lands, would initially act as a price stabilizer, followed by a later reduction of prices. Based on a balanced supply - demand approach, the FSMs also allowed for estimating the impact of alternative policies on consumer and producer groups to address the conflict, elicit in the 1970s, over public forest lands for commodity and non-commodity uses as these models computed consumer and producers surplus to estimate distributional impacts of policy shifts (Adams & Haynes 2007a).

There is a large body of literature on other policy analyses conducted during the 1990s with the help of the FSMs (those in the TAPS and others developed after 1980). A 1997 paper by Sedjo & Goetzel (1997) titled “Workshop to Examine Models Needed to Assist in the Development of a National Fiber Supply Strategy for the 21st Century”, provides relevant examples that illustrate how FSMs were not only used to address commodity policy concerns but also to address environmental policy questions, as the two below:

a) In 1992-1993, the International Institute for Environment and Development (IIED) carried out a study for the International Tropical Timber Organization (ITTO), to potentially use trade instruments to encourage more sustainable forest management in the tropics. Using the Cintrafor GTM to develop a set of forecasts and policy simulations, the IIED was able to conclude that “unilateral imposition of barriers to trade in tropical timber by importing countries would not help to encourage better forest management in the tropics, and might even hurt, by depressing producer prices and thus reducing the economic incentives to invest in forestry” and “to show the potential cost of trade barriers to developing countries, in terms of reduced market share and export revenues, as well as the likely impact on consumers through higher product prices" (Bishop 1997).

b) Winnett (1997) reported the use of FSMs by Climate Change policy analysis at the Environmental Protection Agency (EPA). Using TAMM/ATLAS and the NAPAP model in conjunction with forest carbon models such as FORCARB, HARVCARB and the EPA's own forest carbon model, EPA examined a number of US "policies to change utilization rates for recycled fiber, increase afforestation on marginal crop and pasture land, change harvest levels (in both directions) on National Forest lands, and use forests for biomass fuels". Combinations of these policies were also examined, "as it is unlikely they would either exist or be implemented singly". The author also reports the use of TAMM/ATLAS and CINTRAFOR-GTM for studying "how these domestic policies would affect international markets, and how carbon sequestration would be affected globally". Perez-Garcia, Joyce, Binkley & Mcguire (1997), documented some of the results of the work at EPA, showing that, as a "result of climate change, net [forest] productivity will apparently increase…unambiguously benefit[ing] consumers of forest products", and that "impacts on producers [were] mixed, but generally negative as prices [would] fall more than output expand". Their paper also shows that "under the scenarios analyzed here, the big consuming economies—the United States, Japan, and Europe—all benefit from climatic change. Two of the most dynamic timber supplying regions—New Zealand and Chile—lose." The author also claimed that latter results could "probably be generalized to other regions which have made major investments in forest plantations for export markets."

Adams & Haynes (2007b) summarize and give multiple examples of the application of forest sector models in forest policy analysis in three broad themes - some of them already explained - that are still valid:

1) The trade-off between commodity and non-market resources values – where forest sector models are used to describe how agents in the market will respond to a policy (e.g. a conservation reserve program), and project the associated timber resource changes

2) Resource planning at a finer scale - to provide geographical detail information on the impact of forest policies in rural areas, where the local effect of policy change might be large (e.g. "loss of the only mill in an isolated community")

3) Forest policy interactions across other sectors - to illustrate how the actions for implementing a forest policy influence the efficacy of other forest-related policies in and out the forest sector - e.g. in the agriculture sector and urban land - and vice versa (e.g. “agricultural policies to subsidize certain crops, or to encourage soil conservation to influence land-use decisions, shifting areas from agriculture to forest cover, or the reverse.”)

The most recent reviews regarding the application of FSM for policy analysis were conducted by Toppinen & Kuuluvainen (2010), Latta et al. (2013) and Rivière & Caurla (2021). These reviews include not just models designed and applied in the US, but also in Europe and other parts of the world. Toppinen and Kuuluvainen report the use of forest sector models in a regional, national, and global context in forecasting the sectoral development, a critical point of the forest policy analysis. They also report their use in addressing policy questions concerning the effects of forest conservation and forest bio-energy. Latta et al. organize the comprehensive list of the usage of forest sector models for policy analysis into three groups: environment, renewable energy, and climate change. Rivière & Caurla (2021) report a prevalence of environmental and climate policy issues treated with the use of FSM with important focus on bioenergy production and carbon sequestration. The EFI – GTM model used by Kallio, Moiseyev, & Solberg (2006), and the GFPM utilized by Buongiorno, Raunikar, & Zhu (2011), are two examples with a detailed illustration of the results of mentioned applications.

The EFI-GTM model was used to clarify distributional and market impacts of conservation of consumers and producers of forest products in Europe. Under a scenario of setting aside 5% of the growing stock available to wood supply in Western Europe for protection at the end of 2007, the model´s results suggested that the projected economic impacts of this policy would be relatively small at the aggregate level. The EFI-GTM model showed that this policy would decrease mechanical forest industry production in Western Europe, whereas the paper and paperboard production would be unaffected.

The GFPM was utilized in conjunction with the United States Forest Products Module (USFPM) to analyze, as part of the 2010 forest resource assessment in USA, the impact of a rapid acceleration of bioenergy demand on the world forest sector. Several scenarios for biofuels demand from the Intergovernmental Panel on Climate Change (IPCC) were used, in order to provide projections to 2030 on production, consumption, and prices, both globally and for the main countries in the forest sector. The results showed that a plausible scenario of a doubling of the rate of bioenergy demand would lead to "the convergence of the price of fuelwood and industrial roundwood, raising the price of industrial roundwood by nearly 30% in 2030. The price of sawnwood and panels would be 15% higher. The price of paper would be 3% higher. Concurrently, the demand for all manufactured wood products would be lower in all countries, but the production would rise in countries with competitive advantage. The global value added in wood processing industries would be 1% lower in 2030. The forest stock would be 2% lower for the world and 4% lower for Asia."

The summary above provides rich evidence of the already established benefits of using FSMs for policy analysis relevant to the forest sector. It also provides the framework for answering the policy analysis questions related to the impact of proposed changes on different elements of the forest sector (expansion of forest planted area, increase in number of suppliers, etc.) on consumption, trade, prices, and other elements of the forest sector markets addressed in the present research.

2.4 Macroeconomic Models and Forest Sector Policy

As mentioned in section 2.1 multisectoral Input-Ouput and General Equilibrium models, which include the forest sector separately, are a viable alternative to FSMs in forest policy analysis. This option has been used to monitor the economic impact that changes in the forest sector would have on other sectors, as well as on the economy as a whole, given that FSMs as being partial equilibrium models only provides information for the forest sector (market/industry) in isolation. Two different cases illustrate the advocacy of using such macroeconomic models instead of a FSM for analyzing forest policy issues: a) when the forest sector makes up for a substantial part of the country's overall economy (Haynes 1993), and b) when studying alternative land use choices for climate change policies (Tian, Sohngen, & Sands 2013).

A detailed summary on the use of macroeconomic models for policy analysis and forecast projections can be found in "Forest Policy Modelling in an Economy-Wide Framework", a chapter written by Alavalapati and Banerjee as part of a 2014 book by Kant and Alavalapati, "Handbook of Forest Resource Economics"(Banerjee & Alavalapati J. 2014). As the authors explain, within the macroeconomic models, the first model to be used was based on an input – output (I-O) approach, modeled after Leontief's Nobel Prize (1973) winning lecture, "Structure Of The World Economy - Outline of a Simple Input-Output Formulation" (Leontief, 1974). Leontief visualized the state of the overall economy (at a country or world level) as a "system of interdependent processes"; where each one of the processes requires a set of inputs in order to produce the required outputs. Dixon, Parmenter, Powell & Wilcoxen (1992) and Shoven (1992) build upon this approach by viewing the economy as knit together by the incorporation of inter-sectoral ties between interdependent industrial sectors.

The I-O models are based on the assumption of fixed input and output prices; they also assume that the amount of inputs required to produce one unit of output is fixed. Furthermore, there are no constraints in the supply of inputs, and the demand for output is exogenous. As Alavalapati, Adamowicz & White (1998) explain, the above constraints have often been the reason for major concerns when assessing the validity of the data output from I-O models. The modeling of the supply side of the forest sector in the present research also indicates that putting no constraints on the supply of inputs is not a viable assumption, as the supply of primary products for this sector also depends on land availability, which is a finite resource.

As a result of attempts to work around the restrictions imposed by the I-O models, the sub-class of macroeconomic models that started gaining more use among researchers and policy makers were General Equilibrium (GE) models, among them the Computable General Equilibrium models (CGE), which, as Banerjee & Alavalapati (2014) clarify, are "an improvement over I-O frameworks because they endogenize the price and demand system, enable substitutability of goods and services in production and demand, include a realistic treatment of factor scarcity, institutions and the macroeconomic environment and allow agent behavior optimization with producers competing for scarce resources and consumer expenditures." CGE models capture the relationship between inter-sectoral transactions, price dependencies, and the agents' behavior (consumers and producers) through a set of mathematical equations, based on economic assumptions derived from theory, complete with market clearing conditions and other economic identities (Dixon et al. 1992). This system of equations is simultaneously solved to find a general equilibrium (Bandara 1991).

As Bandara (1991) expounds, the selection of parameter values for the functional forms, known as 'calibration' in the CGE modelling literature, is extremely important in determining the results of policy simulations of CGE models. In order to calibrate a CGE model, the Social Accounting Matrix (SAM) data framework and various elasticity estimates are used. The SAM provides an empirical description of the structure of production and transactions between sectors, institutions and factors of production for a representative base year (Banerjee & Alavalapati 2014), with its purpose being the organization of data in a transparent way; while it also provides the value of some of the key parameters necessary for the implementation of the model (Bandara 1991). The SAM was developed in the 1970s in developing countries to fill the data gap in I-O tables and national accounts data. This data framework is enriched with government surveys such as household expenditure surveys and agricultural census data.

A CGE model may be a static one-period (comparative-static) model, or a dynamic multi-period one. Comparative-static CGE models map the reaction of the economy at only one point in time. They are used for estimating the order of magnitude and direction of effect of a policy shock, and depending on the model closure, they can have both short-run and long run applications (Banerjee & Alavalapati 2014). On the other hand, Dynamic CGE (DCGE) models trace each variable through time at a properly defined interval. They shed light on the economic transition path resulting from a policy shock, including long-term gains of such policy and its short-term costs (Cattaneo 1999). Banerjee & Alavalapati (2014) further explain that “DCGE models involve a deeper treatment of investment behavior and enable the modeler to update key growth parameters such as population, labor force, factor productivity, world prices, and government consumption. As such, CGE models are considered flexible and powerful in assessing economy-wide and distributional impacts of a policy change, by effectively incorporating inter-sectoral dynamics (Beutre, Rodriguez & Pant 2003).

The use of CGE models for forest sector analysis became popular in the 1990s. Haynes (1993) provides one of the first summaries on the link of forest sector models with macroeconomic models, by making a similar claim that CGE models had particularly proven “useful because of their ability to capture the inter-sectoral economic adjustments whenever they exist in the economy.” This link became more justified in cases like the Indonesian economy (Constantino 1992) where the forest sector had such a significant role in the country’s overall economy that treating it as exogenous would not properly capture the effects that a change in the Indonesian forest market would have on other sectors of its economy. The Indonesian model developed by Dee (1991) which evaluates the impact on the country’s stumpage and discount rates caused by increasing the minimum harvest age and variation, is one of the first accounts of such types of models. Other work done within the same decade includes the CGE modeling of Brazilian macroeconomic policy impacts on forestry by Wiebelt (1994), the study by Alavalapati, White, Jagger, & Wellstead (1998) involving simulations on land-use restrictions and their impact on the economy of Alberta, Canada, followed by the CGE analysis by Alavalapati, Percy, & Luckert, (1997) of the impacts of an increase in the price of stumpage in the province of British Columbia, Canada, and the GE framework used by Thompson, van Kooten, & Vertinsky (1997) in assessing forest management choices available for timber and non-timber values.

In the decade that followed, some of the studies that use CGE models to analyze the impact of forest sector changes in other sectors of the economy include: Dufournaud, Jerrett, Quinn, & Maclaren (2000), who study the economic impact of a ban in forest product exports and other trade restrictions in Vietnam; Gan (2004) with his paper on potential changes in the global forest market initiated by China's trade liberalization policies; followed by a 2005 paper by the same author on forest certification costs and their influence on the global forest markets (Gan, 2005). Another study, around the same time, comes from Stenberg & Siriwardana (2005), which explores the benefits of using a CGE model in analyzing the effects of deforestation on the Philippine economy; while work from Banerjee & Alavalapati (2010) provides an analysis of forest concessions in Brazil under both legal and illegal deforestation scenarios.

With the recent intensification of climate change policies, as well as the increasing interest in using wood biomass as a source of energy (Tian et al. 2013), significant efforts are being made to create a more inclusive global platform of CGE models, with initiatives like The Global Trade Analysis Project (GTAP) at Purdue University, whose mandate is to ensure global collaboration through new software and continuous training. In their chapter, Banerjee and Alavalapati list another institution with great influence in the field – the Centre of Policy Studies (CoPS), from Monash University in Australia, which has provided policy makers worldwide with a number of CGE models, including ORANI, MONASH and TERM, and which has also developed and maintains its own modeling software program, GEMPACK. EcoMod is another global economic modeling network of more than 3.000 members that provides similar services to both policy makers and other end users. Finally, the Partnership for Economic Policy (PEP), with over 8.000 members, uses CGE models as an analytical approach, while focusing on increasing participation rates of local experts in discussions related to poverty alleviation and socioeconomic development.

2.5 Linking Partial and General Equilibrium Models for Policy Analysis

In addition to the use of FSMs and (multisectoral) macroeconomic models to analyze forest policy issues as explained in previous sections, the use of both type of models at the same time in a unique framework model is a third option. However, this approach is rather uncommon in the academic literature. The papers “The Canadian forest product sector: a sectoral econometric model” by Kant et al. (1996) and the “Impacts of combining partial and general equilibrium modelling in freight transport analyses – a forest sector case study” by Madslien et al (2011) are unique cases of it. Of particular interest for the purpose of the present research is the first one. Kant et al. developed a sectoral (partial equilibrium-PE) econometric model for the Canadian forest product sector (CFPSM), concentrating on three forest product industries: wood, furniture, and pulp and paper. For each industry, the model includes behavioral equations that capture total output, consumption, trade (exports & imports), prices for consumption and for each component of trade, and market-clearing condition identities for each of the three industries, as well as summation identities to comply with macroeconomic theory. The model is embedding within the framework of an existing macroeconomic model called FOCUS (Dungan, Murphy, & and Wilson 1995), developed at the Institute for Policy Analysis at the University of Toronto, Canada. The links between the partial and general equilibrium happens in two directions: “i) some endogenous variables of the macroeconomic [GE] model are used as exogenous variables in the sectoral [PE] model and ii) the equations of the sectoral [PE] model are added to the macroeconomic [GE] model and the corresponding equations of the macroeconomic model are re-estimated” (Kant et al. 1996). In their paper, Kant et al. concentrated the attention to the first link by obtaining endogenous variables calculated by the FOCUS model, input them as exogenous variables in its simultaneous set of equations of the CFPSM and generate forecast simulations focused on understanding how the Canadian forest product sector behaves in the context of the country’s overall economy. The first link which helps to understand the effect of the Canadian forest product sector on the performance of the Canada’s economy was not presented. The approach used by Kant et al. to both represent a part of the forest sector in building the PE model that represent it and to embed a PE into a GE model, to study widely the impacts of forest policy in the forest sector and the national economy, at the beginning, is fully applicable to the development of forest sector models in countries in the tropical region where “lack of data” is a constrain.

2.6 Colombian Forest Sector and Forest Plantation Policy

Colombia is a tropical country located at the northwestern part of South America, whose continental area comprises 114.1 million hectares. It is considered a developing country (United Nations, 2015), holding an estimated population of 48.2 million people in 2015 (DANE, 2010). The World Bank 2014 ranking of world economies placed Colombia 31st - after Brazil, Argentina, and Venezuela in South America - with a GDP of USD 337.7 billion (The World Bank, 2015). Colombia´s economy comprises mainly service activities; manufacturing and agricultural activities are relatively minor – contributing with about 11% and 6.1% in Colombia´s GDP for 2014, respectively (DANE, 2015a).

2.6.1 The Colombian Forest Sector – Key Information

As measure by the National Accounts of Colombia, forest sector contribution to the Colombian economy has been historically small. In 2014 this contribution reached 1.19% of its GDP, distributed into forestry (0.3%), the timber and wood industry (0.35%) and the Pulp, Paper, and Paperboard industry and printing (0.54%).

Although natural forests cover 52.7% (58.5 million ha, figure 2-2) of its continental area (IDEAM, 2015), and its potential land for commercial forest plantation development has been estimated in 24.8 million ha, as showed in figure 2-3 (UPRA, 2014), Colombia´s domestic production of industrial round wood in 2013 accounted for only 3.3 million m^3 (DANE, 2015b), and its commercial forest plantations (figure 2-3) covered just 0.48 million ha (The World Bank, National Planning Department of Colombia, Ministry of Agriculture of Colombia, & Profor, 2015)

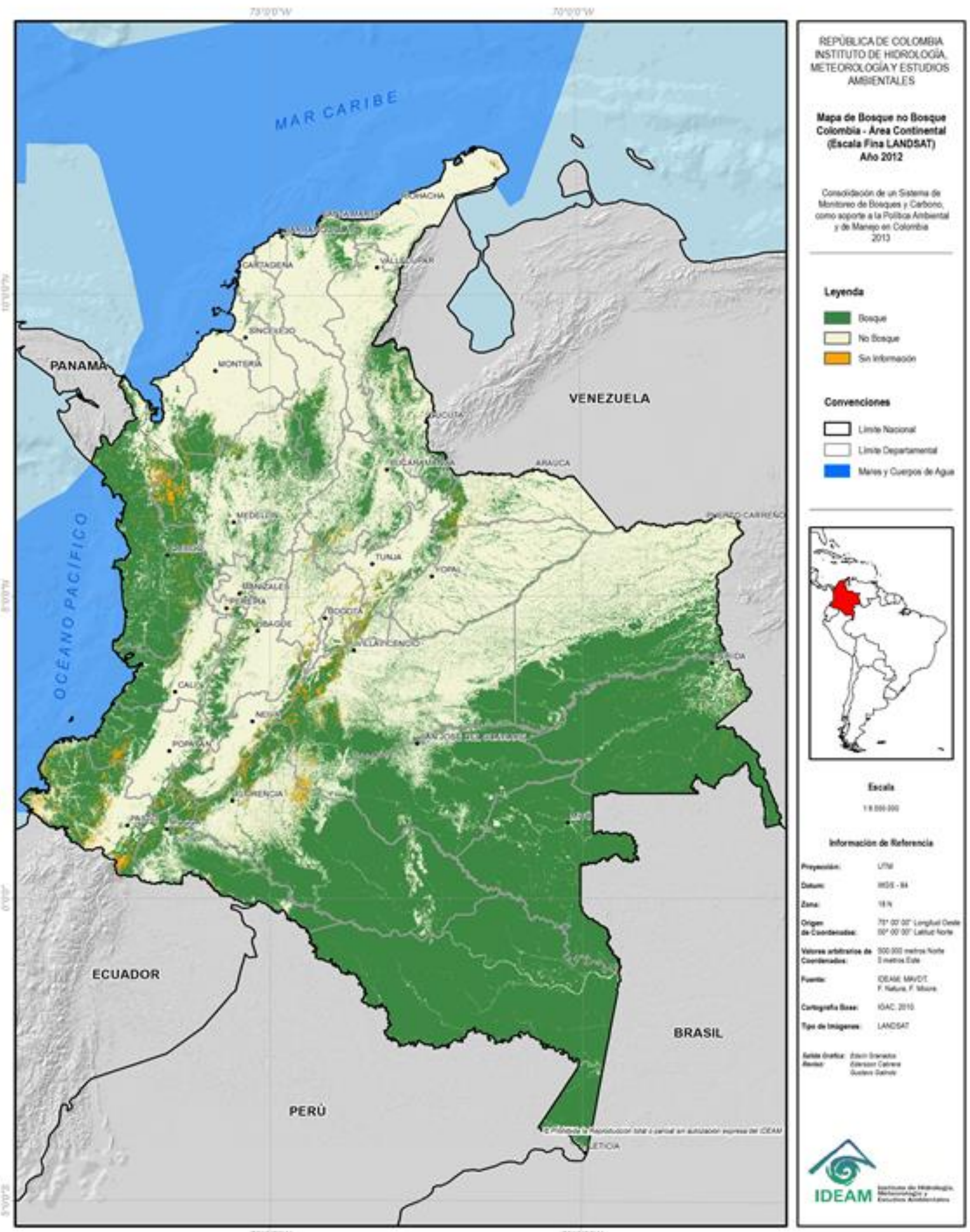
Comparing the most current available data (DANE, 2015a; IDEAM, 2013) against statistics published in 1972 (FEDESARROLLO, 1972), one can find that in the last 43 years, Colombia has lost 10 million ha of its forest cover. Furthermore, it has reduced its forest area under management (concessions and permits) from 1.3 million ha in 1968 to roughly 0.037 million ha in 2011 (under short-term permits of 1 to 2 years), and for the last 10 years, remained at the 1969-level of industrial round wood production (3.2 million cubic meters), and exports (USD 13.7 million).

Diverse forest agents interact in the same forest market in Colombia: forest owners (suppliers of timber) and producers and consumers. Forest owners are clearly separated in two groups: natural forest owners and planted forest owners. Afro-American communities, Indigenous peoples, and the State own almost all land pertaining to natural forests; tenure of the first two reaches 53% (31.8 million ha) of all natural forests. Forest plantation owners are usually non-communal-private industrial ones; their forest area is still small (0,5 million ha, with six species making up for 90% of the distribution), but given the fact that the commercial forest plantation potential land has been estimated at 25 million ha, there is an enormous interest on this area being increased. Forest plantation owners are clearly responsive to timber market prices, and some might also be playing in both markets: timber and carbon offsets.

Industry producers in Colombia include a scattered, large number of small-size firms in the Sawmill Industry, seven plants representing the wood-based panels industry, one mill in the Wood pulp industry, and at least 10 plants in the Paper Industries, all of them price responsive. The Sawmill Industry is distributed all over the five natural regions in Colombia, while the wood pulp mill, paper and board plants are confined to the three natural regions (Central, Caribe, Orinoquia), where a big portion of potential land for commercial forest plantation is also located.

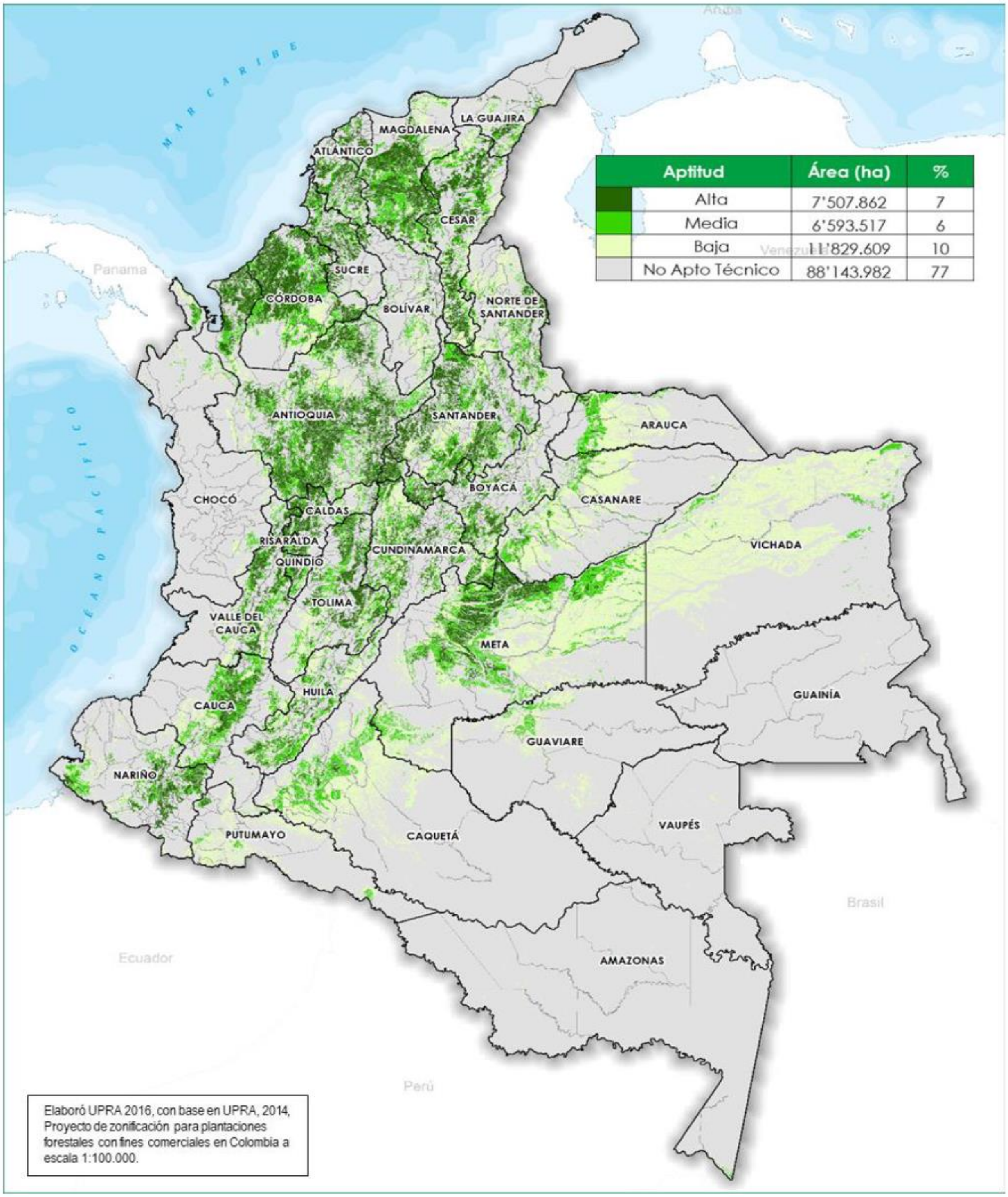
Wood forest products consumers are spread all over the country, but major consumer centres are concentrated in the capital and mid size cities in the Central and Caribe regions, the latter located at the northern part of the country. Colombia exports negligible quantities of wood forest products. In the global context, quantities of wood forest products imported by Colombia are also marginal. Nevertheless, in the context of demand at national levels, Colombia is a big importer of wood pulp and wood-based boards (in 2013, 35% of the 5.5 million cubic meters demanded for wood primary products, such as pulp, wood-based boards, and wood-industry-related products were imported, while only 3% were exported - (Held, et al., 2017)).

Figure 2-2 Colombia´s Natural Forest Area



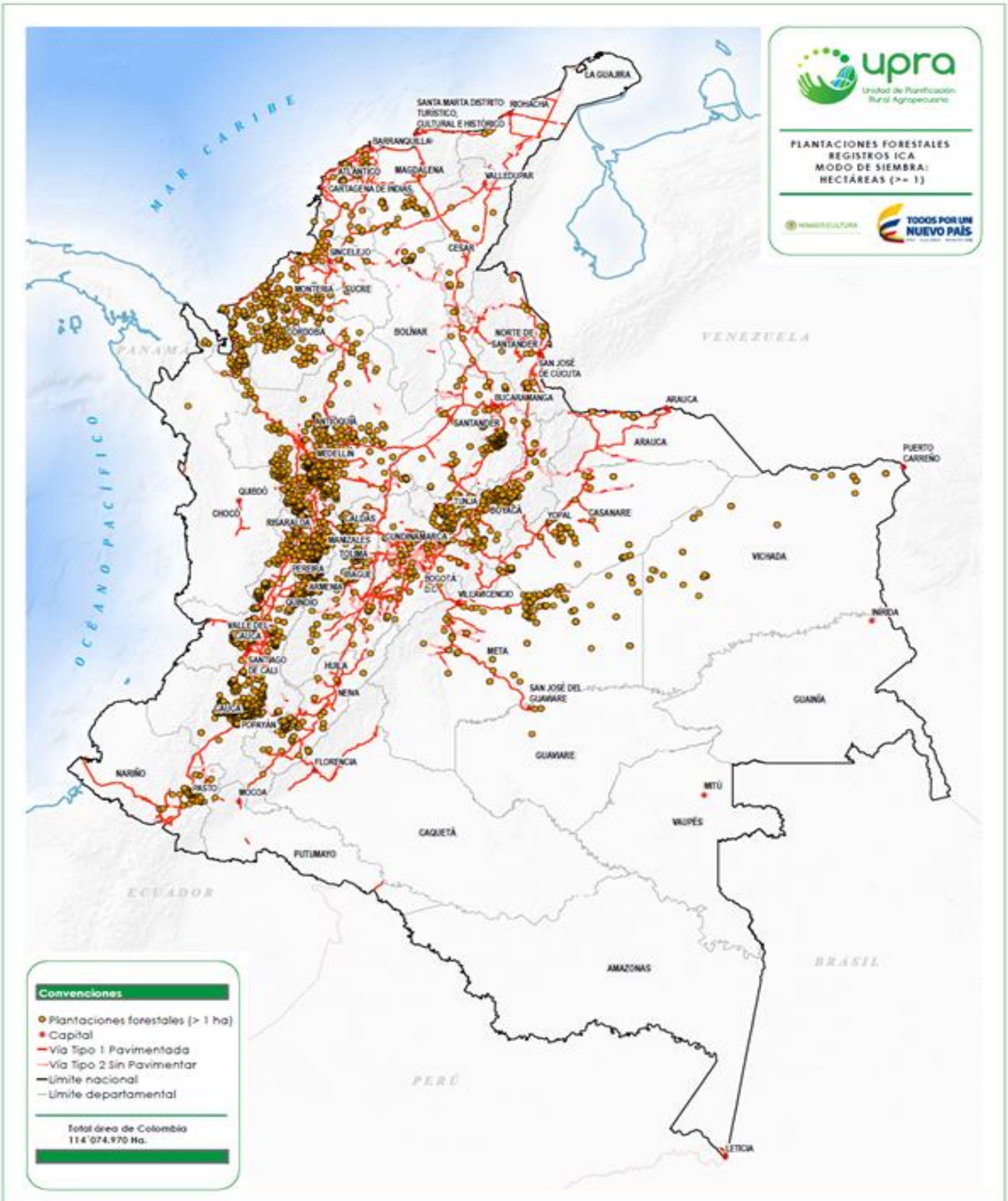
Source: IDEAM, 2015. Areas covered by natural forests in green; areas without information in brown.

Figure 2-3 Colombia´s potential area for forest plantation development



Source: UPRA, 2015. In dark green the areas with the best potential for forest plantation development, in light green the areas with second best potential, and in yellow the areas with third best potential.

Figure 2-4 Colombia´s commercial forest plantations (December 2015)



Source: UPRA 2017 (Not official, without scale, only prepared for the CFSM use). Yellow dots represent the forest plantation stands and have been exaggerated in order to get a better view of the forest plantation location. Red lines represent major highway

2.6.2 Colombian Forest Development and Forest Policy

Forest development in Colombia is led by four national governmental institutions whose governance covers one or more aspects of the forest sector: the Ministry of Agricultural and Rural Development (MADR), the Ministry of Environment and Sustainable Development (MADS), the Ministry of Industry, Trade and Tourism (MINCIT) and the National Department of Planning (DNP). Governance of MARD comprises all aspects related to the production of goods from the commercial forest plantations and the natural forests (integrated into the forest value chain concept) and the current and potential lands to produce forest goods located into the agricultural land frontier. MADS' authority involves the issues related with the conservation and protection and sustainable management of forests and forest lands (excluding commercial forest plantations and lands for forest production into the agricultural land frontier), the production of forest ecosystem services and environmental issues of the forest sector. MINCIT's governance encompasses all the aspects related to industry, trade and tourism of the forest sector while DNP's authority is extensive to the planning of the forest sector development. Although Forest National Service (FNS) was created by law in 1989, so far it has not been put into operation. MADR, MADS, MINCIT and DNP are the institutions in charge of directing the policy process (formulation, implementation, follow-up, and evaluation) of the forest policy in Colombia. The implementation of the policy is carried out by the national organizations ascribed to these four ministries, 33 regional environmental authorities and the departments and municipalities that conform the political division of Colombia.

Forest policy is devised in several documents at the national, regional, and local levels. The National Policy of Forests (1996), the 2000-2025 Forest Development National Plan (2000) and the 2018-2038 Commercial Forest Plantation Value Chain Policy (2019) are considered in Colombia the main policy documents at the national level. These three policies contain the long-term vision of the Colombia's forest sector shared by main stakeholders, the strategic objectives to develop and consolidate the forest sector, and the goals, programs, projects and tasks to be implemented in order to reach these aims.

As forests has become an important topic in international deliberations about climate change, biodiversity and desertification, among other multilateral conversations, and Colombia experience several issues related to its forests, policy documents for the forest sector also encompasses other national policies such as the Forest Preventing, Following-up, Control and Invigilating National Strategy (2010), the Adaptation for Climate Change National Plan and Low Carbon Development Colombian Strategy (2011), the National Strategy for Deforestation and Forest Degradation Emission Reduction ENREDD+ (2011), the National Policy for Integral Management of Biodiversity and Ecosystem Services (2012) and its Biodiversity Action Plan (2017), the National Plan for Ecologic Restoration, Recovering and Reclaiming Disturbing Areas (2015), the Policy Guidelines and Action Plan of Payment for Environmental Services (2017), the Green Growth Policy (2018), the Strategy for Implementing the Sustainable Development Goals (2018), and, finally, the 2020-2030 National Policy for controlling deforestation and improving sustainable management of forests (2020).

2.6.2.1 2018-2038 Commercial Forest Plantation Value Chain Policy (PFCm policy)

The PFCm policy, officially released in June 2019 (MADR 2019a), is set up in two documents: “Policy guidelines for commercial forest plantation for wood production (PFCm) value chain” (Martínez-Cortés 2017a) and “Action plan for the development and consolidation of commercial forest plantation for wood production value chain” (Martínez Cortés 2017b). These documents contain the results of the strategic planning process carried out by the main stakeholders of the PFCm value chain to continue its development and consolidation. This policy is set to be implemented in three time-periods during the next 20 years, as follows: 2018-2022, 2023-2030, and 2031-2038, each period to be evaluated against the original 22 strategic objectives and their goals. Strategic Objectives have been organized into four groups called Strategic Axes of the Policy: Productivity and Markets, Institutional Framework, Social Inclusion and Decent Work, and Environmental Commitment.

Goals to be reached under the Productivity and Markets axe comprise: a threefold increase in the area of PFCm to reach 1,500,000 in 2025 ha to be managed under sustainable forest management principles, a 50% increase in consumption of wood forest products with respect to the 2013-levels (wrt 2013-levels) estimated in 12.2 m^3/1000 people; a 50% rise wrt 2013-levels in the share of wood and its manufactured products in the national market segments of construction, furniture, wood based panels, pulp, paper and paperboard and pallets; a positive trade balance with 60% of the national production exported, 300 MW of forest bioenergy as part of the Colombia’s energy matrix and industrial production of biocomposites and products derived from wood for the chemical, cosmetic and food industries, an increase of 20% in the productivity of the PFCm value chain wrt 2013-levels and quality of wood produced similar to the standards of the international players in the wood and wood products markets, the increase of the national forest industry and, finally, that most of the demand for wood and manufactured wood products is met by the wood coming from commercial-forest-plantation-for-wood-production national source. Other goals, programs, projects and tasks, finances and all other aspects necessary to the implementation of the the PFCm policy are presented in detail in the documents cited.

Chapter 3
Structure and Specification of the Colombian Forest Sector Model - CFSM (Theoretical Approach, Conceptual Mapping and Formulation)

In building and using the CFSM, the following four steps were used: 1. Structure and Specification, 2. Calibration (Data consolidation), 3. Calibration (Estimation) and Validation and 4. Applications. Three first steps are clearly identified with the mentioned names, while the fourth corresponds to the use of the simulator for forest plantations SCRPFC (chapter 6) and the complete CFSM (chapter 7) [5].

3.1 Description of markets, products, model phases and components of the CFSM

The Colombian Forest Sector Model is a partial equilibrium structural econometric model for Colombia´s forest sector. Using the framework of neoclassical theory of competitive markets, and a system of simultaneous linear equations to represent the forest sector, it maps two different markets: the unprocessed forest products market and the manufactured forest products market. Unprocessed forest products include wood and non-wood forest goods at the state they are in when harvested (i.e., without any or with minimal transformation process) from the forest ecosystems (natural forests, planted forest and agroforestry systems, and trees outside forests), and forest ecosystem services. Manufactured forest products consist of wood and non-wood forest goods produced by the manufacturing industry. As the number of forest goods and ecosystem services is vast, the CFSM is developed in phases, which add incremental complexity to the model, as well

[5] There are several forms of dividing the methodological stages in which an economic model is built and used. The next are two examples. a) Following the traditional econometric methodology they can be divided it into eight steps (Gujarati and Porter 2009, p. 3), named: 1. Statement of theory or hypothesis, 2. Specification of the mathematical model of the theory, 3. Specification of the statistical, or econometric, model, 4. Obtaining the data, 5. Estimation of the parameters of the econometric model, 6. Hypothesis testing, 7. Forecasting or prediction, and 8. Using the model for control or policy purposes. b) Following a practical approach, in building its dynamic spatial equilibrium Global Forest Products Model GPM, Buongiorno et al. (2003) divide they into five steps: 1. Structure, 2. Formulation, 3. Calibration, 4. Validation and 5. Applications. Steps 1 and 2 (Specification) of Buongiorno et al.´s are almost equivalent to steps 1 to 3 of Gujarati and Porter´s, steps 3 and 4 of Buongiorno et al.´s could be considered equivalent to all things developed in steps 4 to 6 of Gujarati and Porter´s and step 5 of Buongiorno et al.´s are equivalent to 7 and 8 of Gujarati and Porter´s.

as additional features and abilities, in order to address more complex forest sector and policy analysis.

Phase I of the CFSM, developed under this research, comprises only wood forest products for both, the unprocessed wood market (also known as the wood market[6], which includes unprocessed wood being used as an input for the manufactured wood forest products industry and for final consumption in fences, rural construction, other rural uses different than firewood, and firewood), and the manufactured wood forest products market (which accounts for products from the wood, furniture, pulp and paper industries)[7]. Additional details of the markets and products considered in Phase I are presented in table 3-1. Phase II, which is outside of the scope of this thesis, will include non-wood forest products (rubber, bamboo, and colophony resin, as the most probable in the short term) and ecosystem services (carbon capture and storage, biodiversity conservation, and water protection, as the most probable).

Phase I of the CFSM provides forecasts of equilibrium prices and quantities in both markets defined in Table 3-1. Each year, the equilibrium in these two markets is calculated using two (sub)models: the Unprocessed Wood Market (sub)model – UWM, and the Manufactured Wood Products Market (sub)model – MWM. Year to year variations are governed by the changes in the explanatory variables of the previous year´s equilibrium prices and quantities, which are used in behavioral equations to compute the new equilibrium outcomes. As some input data for the CFMS is in physical values and other in monetary values, units of conversion are utilized when required.

At this time, it is foreseeable that the theoretical approach and the components of the CFSM used for Phase I, with some adjustments, can also be used to model non-wood forest products and forest ecosystem services in Phase II of the CFSM. A complete conceptual map for the development of the CFSM is presented in figure 3-1. Additional details for Phase I are shown in figure 3-2.

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[6] In Colombia "wood market" is used to denominate different markets. Sometimes this expression is used for the general commodity known as wood or wood in the rough, but also for the market of several manufactured wood products (e.g. sawn wood, roundwood), or the market of wood and manufactured-wood products in general.

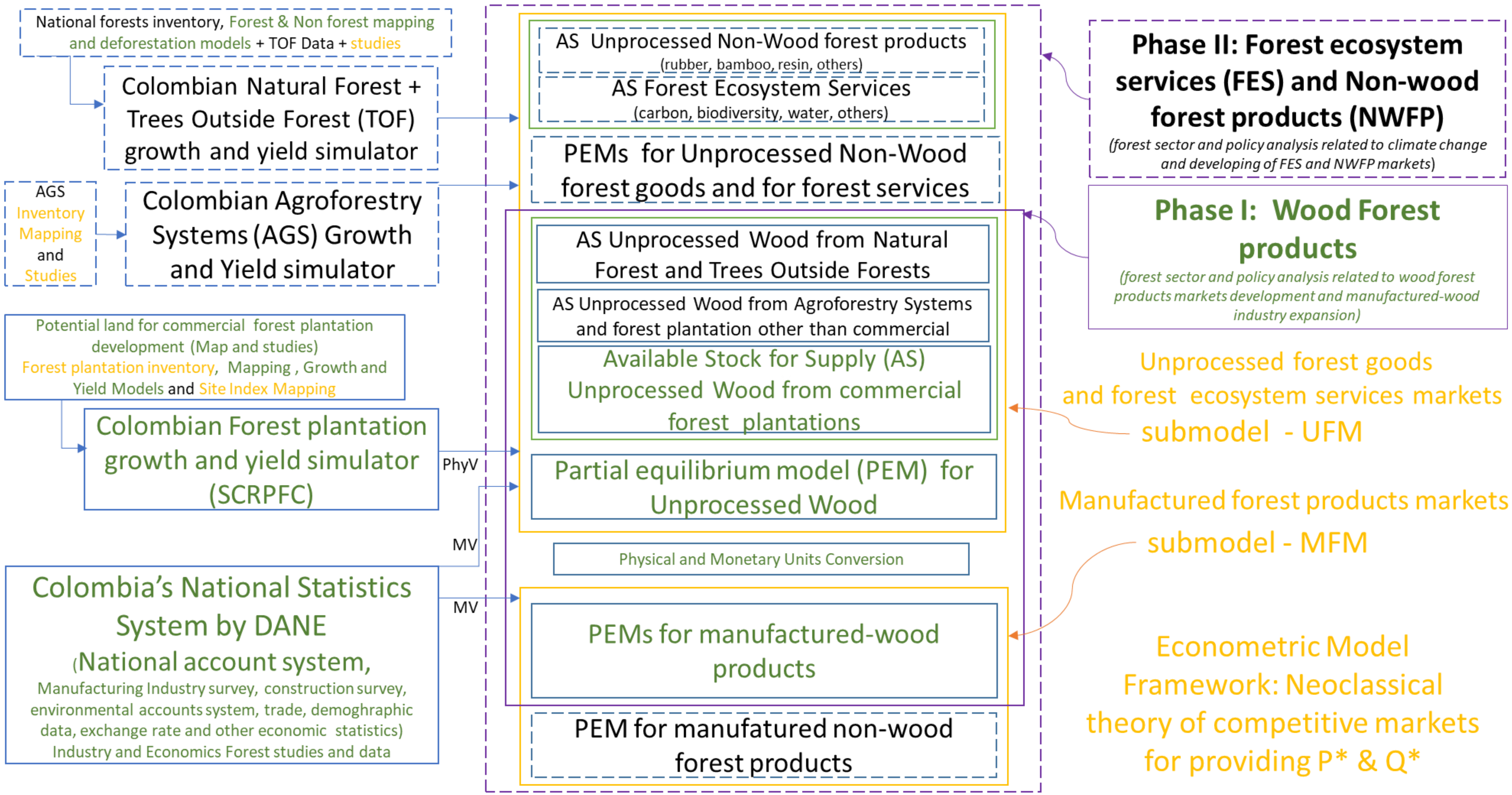
[7] Forest bioenergy & other innovative manufactured wood forest products industries (forest bio-composites, wood products for chemical, cosmetic and food industries) were originally considered as part of Phase I. However, data for these industries was not available as they have only now begun to surface in Colombia (e.g. forest bioenergy), hence, these industries were not included in the analysis for Phase I. Forest bioenergy industry includes pellets, briquettes, and other compressed wood for producing energy, and electric and thermal energy produced by forest biomass – forest feedstocks, waste or residues of the forest industries- in industrial plants.

Table 3-1Markets and Products modelled in Phase I of the CFSM

Markets	(Sub)market or product(s)	Details/ Classes of CPC Ver.2 subclasses to ISIC Rev.4 and HS 2007	Colombia's National Account System base 2015. Classes of the CPC Vers. 2 adapted for Colombia	Colombia's National Account System base 2015. Subclasses of the CPC Vers. 2 adapted for Colombia	Colombia's National Account System base 2015. Groups of ISIC Rev. 4 adapted for Colombia
Unprocessed wood (UW)	UW for the manufactured wood products industry	Wood in the rough (031): logs of coniferous and non-coniferous wood. It is harvested in the commercial forest plantations by a combination of formal logging industry (which serves the pulp and paper, wood based panels, and some part of the sawnwood industry), and an undetermined number of persons (less formally organized than the logging industry from an operational perspective) dedicated to buying private stumpage and harvesting it mainly to supply the sawnwood industry. With some minor exceptions, the country has no logging industry for wood harvesting from natural forests. Wood harvesting from this type of forest is performed by thousands of people who usually live inside or close to the forest areas, countrywide, who usually fell trees and convert them to squared wood (bloques, in Spanish) by using chainsaws, accumulate a certain volume of wood, and then sell it to an intermediary who, in turn, collects wood from different people, transports it and sells it in the main cities, mainly to hundreds of establishments of the sawnwood industry.	30101	03110, 03120	0220
	UW for final consumption other than firewood	Wood in the rough (031): logs of coniferous and non-coniferous wood. In Colombia, wood harvested for final consumption in fences, rural construction, and other rural uses different to firewood originates mainly from natural forests and trees outside forests. This wood is harvested and/or removed by people dedicated to this activity, countrywide, who sell this wood directly to the consumer in the rural areas. Usually trees are felled and converted to squared wood (bloques, in Spanish) by using chainsaws, accumulate a certain volume of wood, and then sell it to final users in rural areas.			
	UW for firewood	Wood in the rough (031) Fuel wood, in logs, in billets, in twigs, in faggots or in similar forms (03130). In Colombia, firewood comprises removals (mostly collected but also harvested) from branches and parts of, or the whole main stem of trees. The removal for firewood is mainly done in the natural forest areas and from trees outside forests but also, marginally, from some agroforestry systems whose main objective is producing firewood. It is the author's understanding, based on the consensus of experts, that there is no formal logging industry involved in this activity. This method is spread in rural areas throughout the country, developed by people from households, and in some cases by individuals dedicated to this activity who sell the firewood to consumers (mostly rural households), in an informal market for which there is scarce or no data	030102	03130	0220
Manufactured wood forest products (MW)	MW from the wood industry	Wood, sawn or chipped lengthwise, sliced or peeled, of a thickness exceeding 6 mm; railway or tramway sleepers (cross-ties) of wood, not impregnated (311); Wood continuously shaped along any of its edges or faces; wood wool; wood flour; wood in chips or particles (312); wood in the rough, including those treated with paint, stains, creosote or other preservatives; railway or tramway sleepers (cross-ties) of wood, impregnated (313), boards and panels (314); veneer sheets; sheets for plywood; densified wood (315), builders' joinery and carpentry of wood (including cellular wood panels, assembled parquet panels, shingles and shakes) (316), packing cases, boxes, crates, drums and similar packings of wood; cable-drums of wood; pallets, box pallets and other load boards, of wood; casks, barrels, vats, tubs and other coopers' products and parts thereof, of wood (including staves) (317), other products of wood; articles of cork, plaiting materials and straw (319) . 3191 other products of wood. Wood and wood product manufacturing services (8831)	310101, 310102, 310200, 310300, 310400	31100, 31210, 31220,31230, 31310, 31320, 31330, 31410, 31420, 31430, 31440, 31450,31510, 31520, 31600, 31911, 31912, 31913, 31914, 31921, 31922, 31923, 31700	1610, 1620, 1630, 1640, 1690
	MW from the furniture industry	Furniture (381): Seats 3811 (seats, primarily with metal frames, seats, primarily with wooden frames, other seats); other furniture, of a kind used in offices 3812 (other metal furniture, of a kind used in offices, other wooden furniture, of a kind used in offices); other wooden furniture, of a kind used in the kitchen, 3813; other furniture n.e.c 3814; mattress supports; mattresses, fitted with springs or stuffed or internally fitted with any material or of cellular rubber or plastics, whether or not covered, 3815, parts of furniture, 3816, furniture manufacturing services (88901).	380100	38111, 38112, 38119, 38121, 38122, 38130, 38140, 38150, 38160	3110, 3120
	MW from the pulp and paper industry	Pulp, paper and paperboard (312) and Paper and paper product manufacturing services (8832).	320100, 320200, 320300	32111, 32112, 32113, 32114, 32115, 32121, 32122, 32128, 32129, 32131, 32132, 32133, 32134, 32135, 32136, 32137, 32138, 32139, 32141, 32142, 32143, 32144, 32148, 32149, 32151, 32152, 32153, 32191, 32192, 32193, 32194, 32195, 32196, 32197, 32198, 32199	1701, 1702, 1709

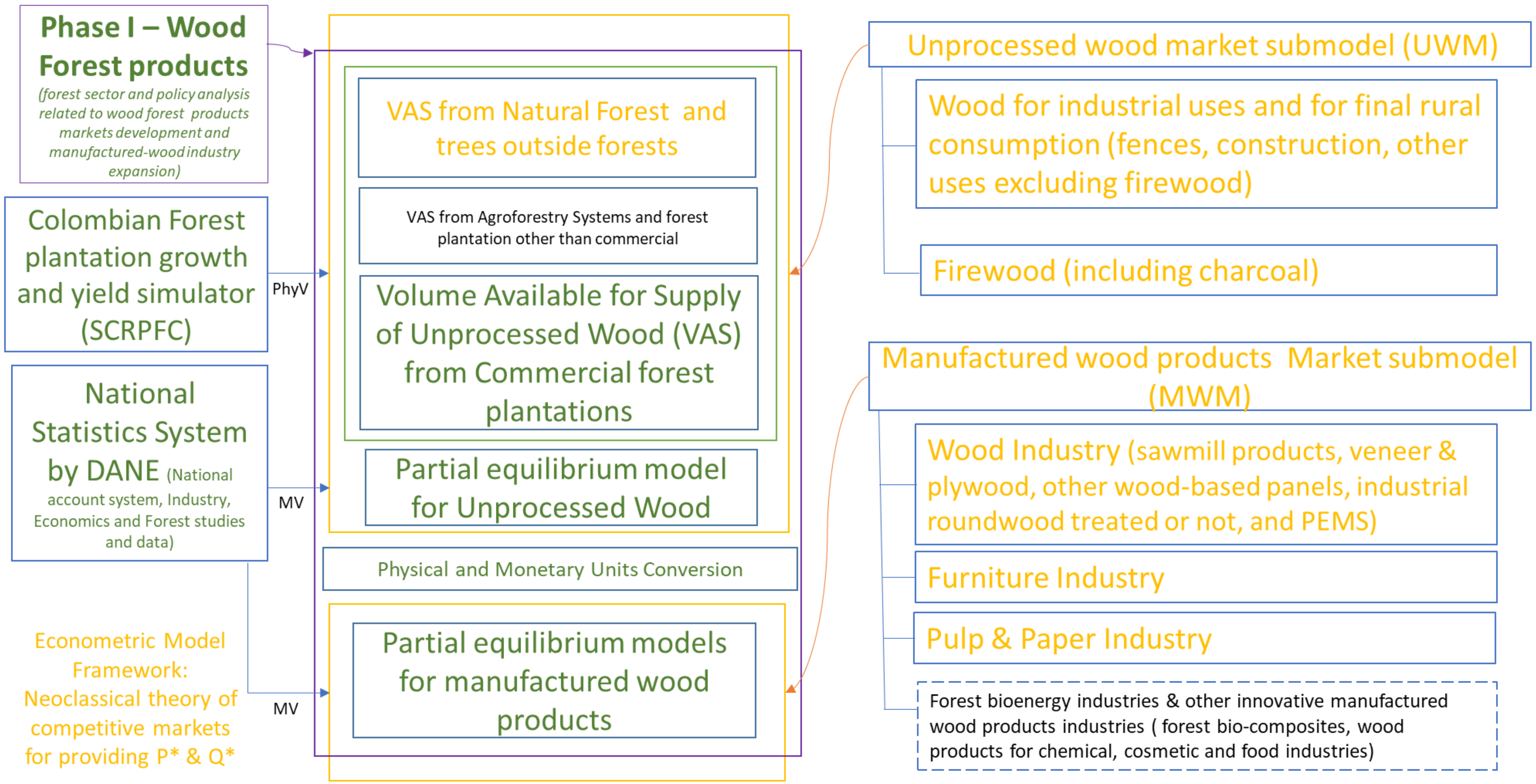
CPC: Central Product Classification, ISIC: International Standard Industrial Classification of All Economic Activities, Rev 4: Revision 4, Ver 2: Version 2, HS: Harmonized System Code. For more details on Classes of CPC Ver.2 subclasses to ISIC Rev.4 and HS 2007 refers to CPC Ver.2 – Detailed structure (unstats.un.org) or https://web.archive.org/web/20161104131035/http://unstats.un.org/unsd/cr/registry/cpc-2.asp. For more details on classification systems for CPC and ISIC adapted for Colombia refer to (dane.gov.co) or https://www.dane.gov.co/index.php/sistema-estadistico-nacional-sen/normas-y-estandares/nomenclaturas-y-clasificaciones/clasificaciones/clasificacion-central-de-productos-cpc. Unprocessed wood for the manufactured wood products industry and unprocessed wood for final consumption other than firewood were aggregated as one market to be modelled in the CFSM given that no separate data is available for those markets.

Figure 3-1 Conceptual map for the Colombian forest sector model (CFSM)



At the center, the CFSM (sub)models: UFM and MFM. At the left, simulators and data needed for Phase I and II of the development of the CFSM. In green: data, inputs and sources available up to 2021 and parts of the UFM and MFM fully developed in Phase I of the CFSM. In yellow data that need to be improved and parts of the UFM and MFM included in Phase I (with full functionality) but that will need more development in Phase II (e.g. UFM (sub)model only includes wood products in Phase I, and only unprocessed wood from commercial forest plantations is fully developed, unprocessed wood from natural forest is incorporated without considering changes in the stock of wood; in Phase II when data from national forest inventory become available, a simulator for the dynamic of natural forest can be developed and incorporated). In black, what is needed for and/or to be developed in Phase II. PhyV: Physical Values, MV: Monetary Values.

Figure 3-2 Conceptual map for Phase I of the Colombian forest sector model (CFSM-I)



At the center, the CFSM (sub)models at Phase I: UWM and MWM. In green: data, inputs and sources available up to 2021 and parts of the UWM and MWM fully developed in Phase I of the CFSM. In yellow data that need to be improved and parts of the UFM and MFM included in Phase I (with full functionality) but that will need more development in Phase II (e.g. UWM (sub)model only includes detailed simulation for calculating the wood supplied by commercial forest plantations, unprocessed wood from natural forest is incorporated without considering changes in the stock of wood, in Phase II when data from national forest inventory become available, a simulator for the dynamic of natural forest can be developed and incorporated). In black, what is needed for and/or to be developed in Phase II. PhyV: Physical Values, MV: Monetary Values.

3.2 Theoretical Structure of the CFSM Phase I (CFSM-I)

As shown in figure 3-2, there are three main components of the CFSM in Phase I: two market (sub)models (MWM and UWM) and one simulator (SCRPFC). The structure of both the MWM and the UWM is explained in the following sections. As the SCRPFC is not a market model but a biological one, its theoretical structure and features are presented in Chapter 6.

3.2.1 Structure of the Manufactured Wood Products Market (sub)model (MWM)

The MWM follows closely the model developed by Kant et al. (1996). It includes a partial equilibrium model for each of the three (sub)markets comprising a group of manufactured wood forest products from the wood, furniture, and pulp and paper industries. Every partial equilibrium model is a system of simultaneous linear equations which includes 7 behavioral equations and one identity for the market clearing condition – MCC. The equations explain seven variables: supply (total production), consumption, exports, imports, and prices of consumption, exports, and imports. Demand is calculated as the sum of consumption plus exports minus imports. The identity (Supply = Demand) is used to determine the overall price if MCC holds; if not, the overall price is an exogenous variable. Four summation identities complete the MWM.

In summary, MWM comprises 21 equation, 5 market-clearing identities and 4 summation identities. To facilitate the summation of different products in each of the three groups of manufactured wood products in the model, MWM is expressed in monetary value terms. Table 3-2 and 3-3 present a summary of the 21 equations and 9 identities of the MWM and their variables, respectively, followed by the economic justifications necessary for the selection of each variable. Factors of conversion used in the MWM are presented in Appendix 3-1.

Table 3-2 Theoretical Equations and Identities for the MWM

Identity or equation number	Identity or Equation name	Identity or General Equation
3-1	Clearing Condition for the manufactured wood products market	$ST_t^{MW} = DT_t^{MW}$
3-2	Total Supply (Production) of manufactured wood products	$ST_t^{MW} = S_t^w + S_t^f + S_t^z$
3-3	Total Demand of manufactured wood products	$DT_t^{MW} = CT_t^{MW} + XT_t^{MW} - MT_t^{MW}$
3-4	Total Consumption of manufactured wood products	$CT_t^{MW} = C_t^w + C_t^f + C_t^z$
3-5	Total Exports of manufactured wood products	$XT_t^{MW} = X_t^w + X_t^f + X_t^z$
3-6	Total Imports of manufactured wood products	$MT_t^{MW} = M_t^w + M_t^f + M_t^z$
3-7	Clearing Condition for market of the manufactured wood products of the wood industry	$S_t^w = C_t^w + X_t^w - M_t^w$ (i.e. $S_t^w = D_t^w$)
3-8	Clearing Condition for Market of the manufactured wood products of the furniture industry	$S_t^f = C_t^f + X_t^f - M_t^f$ (i.e. $S_t^f = D_t^f$)
3-9	Clearing Condition for market of the manufactured wood products of the pulp and paper industry	$S_t^z = C_t^z + X_t^z - M_t^z$ (i.e. $S_t^z = D_t^z$)
3-10	Supply (Production) of manufactured wood products of the wood industry	$S_t^w = \beta_1^{sw} + \beta_2^{sw} PS_t^w + \beta_3^{sw} L_t^w + \beta_4^{sw} K_t^w + \beta_5^{sw} PC_t^{MWrw} + \varepsilon_t^{sw}$
3-11	Supply (Production) of manufactured wood products of the furniture industry	$S_t^f = \beta_1^{sf} + \beta_2^{sf} PS_t^f + \beta_3^{sf} L_t^f + \beta_4^{sf} K_t^f + \beta_5^{sf} PC_t^{MWrw} + \varepsilon_t^{sf}$
3-12	Supply (Production) of manufactured wood products of the pulp and paper industry	$S_t^z = \beta_1^{sz} + \beta_2^{sz} PS_t^z + \beta_3^{sz} L_t^z + \beta_4^{sz} K_t^z + \beta_5^{sz} PC_t^{MWrw} + \varepsilon_t^{sz}$
3-13	Consumption of manufactured wood products of the wood industry	$C_t^w = \beta_1^{cw} + \beta_2^{cw} PC_t^w + \beta_3^{cw} U_t + \beta_4^{cw} i_t + \beta_5^{cw} W_t + \beta_6^{cw} HCS_t + \beta_7^{cf} Y_t + \varepsilon_t^{cw}$
3-14	Consumption of manufactured wood products of the furniture industry	$C_t^f = \beta_1^{cf} + \beta_2^{cf} PC_t^f + \beta_3^{cf} U_t + \beta_4^{cf} i_t + \beta_5^{cf} W_t + \beta_6^{cf} HCS_t + \beta_7^{cf} Y_t + \varepsilon_t^{cf}$
3-15	Consumption of manufactured wood products of the pulp and paper industry	$C_t^z = \beta_1^{cz} + \beta_2^{cz} PC_t^z + \beta_3^{cz} U_t + \beta_4^{cz} i_t + \beta_5^{cz} W_t + \beta_6^{cz} N_t + \beta_7^{cf} Y_t + \varepsilon_t^{cz}$
3-16	Exports of manufactured wood products of the wood industry	$X_t^w = \beta_1^{xw} + \beta_2^{xw} IPI_t + \beta_3^{xw} PX_t^w/RX_t + \varepsilon_t^{xw}$
3-17	Exports of manufactured wood products of the furniture industry	$X_t^f = \beta_1^{xf} + \beta_2^{xf} IPI_t + \beta_3^{xf} PX_t^f/RX_t + \varepsilon_t^{xf}$
3-18	Exports of manufactured wood products of the pulp and paper industry	$X_t^z = \beta_1^{xz} + \beta_2^{xz} IPI_t + \beta_3^{xz} PX_t^z/RX_t + \varepsilon_t^{xz}$
3-19	Imports of manufactured wood products of the wood industry	$M_t^w = \beta_1^{mw} + \beta_2^{mw} C_t^w + \beta_3^{mw} PC_t^w/PM_t^w + \beta_4^{mw} CUR_t^w + \varepsilon_t^{mw}$
3-20	Imports of manufactured wood products of the furniture industry	$M_t^f = \beta_1^{mf} + \beta_2^{mf} C_t^f + \beta_3^{mf} PC_t^f/PM_t^f + \beta_4^{mf} CUR_t^f + \varepsilon_t^{mf}$
3-21	Imports of manufactured wood products of the pulp and paper industry	$M_t^z = \beta_1^{mz} + \beta_2^{mz} C_t^z + \beta_3^{mz} PC_t^z/PM_t^z + \beta_4^{mz} CUR_t^z + \varepsilon_t^{mz}$
3-22	Consumption price of manufactured wood products of the wood industry	$PC_t^w = \beta_1^{pcw} + \beta_2^{pcw} S_t^w + \beta_3^{pcw} PC_{t-1}^w + \varepsilon_t^{pcw}$
3-23	Consumption price of manufactured wood products of the furniture industry	$PC_t^f = \beta_1^{pcf} + \beta_2^{pcf} S_t^w + \beta_3^{pcf} PC_{t-1}^f + \varepsilon_t^{pcf}$
3-24	Consumption price of manufactured wood products of the pulp and paper industry	$PC_t^z = \beta_1^{pcz} + \beta_2^{pcz} S_t^z + \beta_3^{pcz} PC_{t-1}^z + \varepsilon_t^{pcz}$
3-25	Export price of manufactured wood products of the wood industry	$PX_t^w = \beta_1^{pxw} + \beta_2^{pxw} PX_{t-1}^w + \beta_3^{pxw} RX_t + \beta_4^{pxw} WEPI_t^w + \varepsilon_t^{pxw}$
3-26	Export price of manufactured wood products of the furniture industry	$PX_t^w = \beta_1^{pxw} + \beta_2^{pxw} PX_{t-1}^w + \beta_3^{pxw} RX_t + \beta_4^{pxw} WEPI_t^f + \varepsilon_t^{pxw}$
3-27	Export price of manufactured wood products of the pulp and paper industry	$PX_t^z = \beta_1^{pxz} + \beta_2^{pxz} PX_{t-1}^z + \beta_3^{pxz} RX_t + \beta_4^{pxz} WEPI_t^z + \varepsilon_t^{pxz}$
3-28	Import price of manufactured wood products of the wood industry	$PM_t^w = \beta_1^{pmw} + \beta_2^{pmw} PM_{t-1}^w + \beta_3^{pmw} PC_t^w/PC_{t-1}^w + \beta_4^{pmw} RX_t + \varepsilon_t^{pmw}$
3-29	Import price of manufactured wood products of the furniture industry	$PM_t^f = \beta_1^{pmf} + \beta_2^{pmf} PM_{t-1}^f + \beta_3^{pmf} PC_t^f / PC_{t-1}^f + \beta_4^{pmf} RX_t + \varepsilon_t^{pmf}$
3-30	Import price of manufactured wood products of the pulp and paper industry	$PM_t^z = \beta_1^{pmz} + \beta_2^{pmz} PM_{t-1}^z + \beta_3^{pmz} PC_t^z/PC_{t-1}^z + \beta_4^{pmz} RX_t + \varepsilon_t^{pmz}$
Variables, and paramters, are to be read as follows:	**$PC_t^z = \beta_1^{pcz} + \beta_2^{pcz} S_t^z + \beta_3^{pcz} PC_{t-1}^z + \varepsilon_t^{pcz}$ (Equation 3 - 24)** PC_t^z : Consumption price of the manufactured wood products of the pulp and paper industry at time t $\beta_1^{pcz}, \beta_2^{pcz}, \beta_3^{pcz}$: Firts (Independent), second and third population parameter of the equation of price of consumption for the manufactured wood products of the pulp and paper industry, repectively. S_t^z : Supply (production) of manufactured wood products of the pulp and paper industry at time t PC_{t-1}^z : Consumption price of the manufactured wood products of the pulp and paper industry at time t-1 (i.e. lagged 1 period) ε_t^{pcz} : Disturbance stochastic term of the equation of price of consumption for the manufactured wood products of the pulp and paper industry at time t	

Table 3-3 Variables used for theoretical equations and identities of the MWM

Variables	Description		Superscripts	Description
C	Consumption		cf	of the equation of consumption of manufactured wood products of the furniture industry
CT	Total consumption		cw	of the equation of consumption of manufactured wood products of the wood industry
CUR	Capacity utilization rate		cz	of the equation of consumption of manufactured wood products of the pulp and paper industry
D	Demand		f	(manufactured wood products of the) furniture industry
DT	Total demand		mf	of the equation of imports of manufactured wood products of the furniture industry
HCS	Housing construction		mw	of the equation of imports of manufactured wood products of the wood industry
i	Inflation		MW	Manufactured wood products
IPI	World's Industrial Production Index		MWrw	Unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood
K	Capital		mz	of the equation of imports of manufactured wood products of the pulp and paper industry
L	Labor		pcf	of the equation of consumption price of manufactured wood products of the furniture industry
M	Imports		pcw	of the equation of consumption price of manufactured wood products of the wood industry
MT	Total imports		pcz	of the equation of consumption price of manufactured wood products of the pulp and paper industry
N	Total Population		pmf	of the equation of imports price of manufactured wood products of the furniture industry
PC	Price of consumption		pmw	of the equation of imports price of manufactured wood products of the wood industry
PM	Price of imports		pmz	of the equation of imports price of manufactured wood products of the pulp and paper industry
PS	Price of supply		pxf	of the equation of exports price of manufactured wood products of the furniture industry
PX	Price of exports		pxw	of the equation of exports price of manufactured wood products of the wood industry
RX	Exchange rate		pxz	of the equation of exports price of manufactured wood products of the pulp and paper industry
S	Supply		sf	of the equation of supply (production) of manufactured wood products of the furniture industry
ST	Total Supply		sw	of the equation of supply (production) of manufactured wood products of the wood industry
U	Unemployment		sz	of the equation of supply (production) of manufactured wood products of the pulp and paper industry
W	Wealth		w	(manufactured wood products of the) wood industry
WEPI	World Exports price Index		xf	of the equation of exports of manufactured wood products of the furniture industry
X	Exports		xw	of the equation of exports of manufactured wood products of the wood industry
XT	Total exports		xz	of the equation of exports of manufactured wood products of the pulp and paper industry
Y	Total income		z	(manufactured wood products of the) pulp (Zellstoff in German) and paper industry
			Subscripts	
			t	time

3.2.1.1 Identities

The Colombian manufactured wood forest products (MW) market is the aggregate of three (sub)markets comprising several manufactured wood products from the wood (w), furniture (f) and pulp and paper (z) industries, respectively. For the MWM, it is assumed that each (sub)market and the aggregate market can be modelled as a system of simultaneous linear equations using the theoretical framework of competitive markets. Hence, summation and clearing condition identities hold in each (sub)market and the aggregated market. Market clearing condition (MCC) requires that the total (T) supply (S) for the manufactured wood forest products and the supply for each group of manufactured wood products considered is equal to its total demand (D) (i.e., consumption plus exports, minus the imports), respectively. Also, the totals for each economic variable of interest: supply (S), consumption (C), exports (X) and imports (M) are given by a linear sum of the subtotals for each group of manufactured wood products considered. Both MCC and summation identities for the aggregate market and the (sub)markets can be written as follows:

$$ST_t^{MW} = DT_t^{MW} \qquad (3\text{-}1)$$

$$ST_t^{MW} = S_t^w + S_t^f + S_t^z \qquad (3\text{-}2)$$

$$DT_t^{MW} = CT_t^{MW} + XT_t^{MW} - MT_t^{MW} \qquad (3\text{-}3)$$

$$CT_t^{MW} = C_t^w + C_t^f + C_t^z \qquad (3\text{-}4)$$

$$XT_t^{MW} = X_t^w + X_t^f + X_t^z \qquad (3\text{-}5)$$

$$MT_t^{MW} = M_t^w + M_t^f + M_t^z \qquad (3\text{-}6)$$

$$S_t^w = C_t^w + X_t^w - M_t^w \quad (\text{i.e., } S_t^w = D_t^w) \qquad (3\text{-}7)$$

$$S_t^f = C_t^f + X_t^f - M_t^f \quad (\text{i.e., } S_t^f = D_t^f) \qquad (3\text{-}8)$$

$$S_t^z = C_t^z + X_t^z - M_t^z \quad (\text{i.e., } S_t^z = D_t^z) \qquad (3\text{-}9)$$

3.2.1.2 Behavioral Equations

3.2.1.2.1 Supply (Production) of manufactured wood products

The Supply equations for the manufactured wood products are regression equations that model the supply for each of the groups of products of the three manufacturing industries (wood, furniture, pulp & paper) as the dependent variable. The explanatory variables of choice are labor (L), capital (K), and prices (P), which are the key factors of production as established by economic theory.

The general equations of the manufactured wood products groups are:

$$S_t^w = \beta_1^{sw} + \beta_2^{sw} PS_t^w + \beta_3^{sw} L_t^w + \beta_4^{sw} K_t^w + \beta_5^{sw} PC_t^{MWrw} + \varepsilon_t^{sw} \qquad (3\text{-}10)$$

$$S_t^f = \beta_1^{sf} + \beta_2^{sf} PS_t^f + \beta_3^{sf} L_t^f + \beta_4^{sf} K_t^f + \beta_5^{sf} PC_t^{MWrw} + \varepsilon_t^{sf} \qquad (3\text{-}11)$$

$$S_t^z = \beta_1^{sz} + \beta_2^{sz} PS_t^z + \beta_3^{sz} L_t^z + \beta_4^{sz} K_t^z + \beta_5^{sz} PC_t^{MWrw} + \varepsilon_t^{sz} \qquad (3\text{-}12)$$

Where PS_t = Price of Supply, and PC_t^{MWrw} = consumption price for unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood [8].

3.2.1.2.2 Demand for manufactured wood products

Consumption (C)

In addition to the usual microeconomic foundation variables of price of consumption (PC) and income (Y), three other macroeconomic variables, namely: unemployment (U), inflation (i) and wealth (W) are used as explanatory variables to model consumption for all manufactured wood products. Consumption for specific manufactured wood products also depends on other explanatory variables based on their use: products from the wood and furniture industries are durable goods, while products from the pulp & paper industry are non-durable goods (Kant et al, 1996). The consumption for products manufactured by the wood industry in Colombia is mainly driven by the housing construction (HCS), which also influences demand for furniture; while

[8] CFSM Phase I assumes there is just one price for all types of wood traded in the market of unprocessed wood for the manufactured wood products industry.

population (N) impacts the demand for the non-durable goods produced by the pulp & paper industry. With these additions, the consumption for each manufactured wood products industry is as follows:

$$C_t^{w} = \beta_1^{cw} + \beta_2^{cw} PC_t^{w} + \beta_3^{cw} U_t + \beta_4^{cw} i_t + \beta_5^{cw} W_t + \beta_6^{cw} HCS_t + \beta_7^{cf} Y_t + \varepsilon_t^{cw} \quad (3\text{-}13)$$

$$C_t^{f} = \beta_1^{cf} + \beta_2^{cf} PC_t^{f} + \beta_3^{cf} U_t + \beta_4^{cf} i_t + \beta_5^{cf} W_t + \beta_6^{cf} HCS_t + \beta_7^{cf} Y_t + \varepsilon_t^{cf} \quad (3\text{-}14)$$

$$C_t^{z} = \beta_1^{cz} + \beta_2^{cz} PC_t^{z} + \beta_3^{cz} U_t + \beta_4^{cz} i_t + \beta_5^{cz} W_t + \beta_6^{cz} N_t + \beta_7^{cf} Y_t + \varepsilon_t^{cz} \quad (3\text{-}15)$$

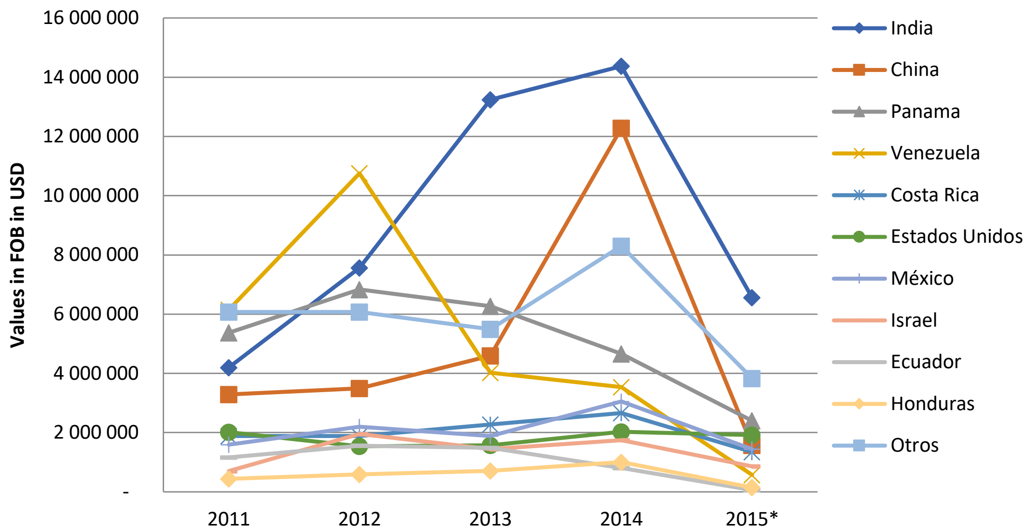
where C^w, C^f, C^z is total consumption of manufactured wood products of the wood (w), furniture (f) and pulp & paper (z) industries , respectively.

Exports (X)

Although natural forests cover 58.5 million ha -half of Colombia´s land (IDEAM, 2015), and the country’s potential land for commercial forest plantation development has been estimated at 24.8 million ha (UPRA, 2014), most of its natural forest are not used for wood production, and the land available for forest plantation development remains untouched. This puts Colombia at a disadvantage when it comes to the export of wood and its products. FAO lists Colombia as 41st in the list of countries that are supplying roundwood for industrial use, contributing with only 0.2% in the total world supply (Ministerio del Medio Ambiente y Desarrollo Sostenible & ONF Andina, 2015).

The main export demand for 2014 came from India, with USD 14.4 million (26.4 %), China with USD 12.3 million (22.6 %), Panama with USD 4.7 million (8.6%) and Venezuela with USD 3.5 million (6.5%), Costa Rica and United States follows (Ministerio del Medio Ambiente y Desarrollo Sostenible & ONF Andina, 2015). Figure 3-3 taken from the same source as the statistics above, gives the distribution of exports of the forest sector for Colombia for the time frame between January 2011 and June 2015. Note that exports to Venezuela, which was the main importer of wood products from Colombia, has declined severely.

Figure 3-3 Colombia - Annual Exports of wood and manufactured wood products



Source: Ministerio del Medio Ambiente y Desarrollo Sostenible & ONF Andina (2015). Estados Unidos = United States of America)

Usually, the main determinants of exports of wood forest products are the prices of exported products, the Industrial Production Index (IPI) for each of the main importers, country-specific exchange rates (RX), as well as any other variables that influence the consumption of the exported product such as population and housing construction activity. Kant at al (1996) used US data for those variables given that USA is the main trade partner of Canada.

It can be seen that no country dominates Colombia's exports. In addition, all exports in this country are traded in USD, and the pool of countries receiving Colombian exports has changed and could continue to change in the future. As such, instead of country-specific indexes, better explanatory variables of wood products exports are the respective prices of exports (PX) for each group of manufactured wood products of the three industries considered, as well as the World's Industrial Production Index (IPI) and Colombia's USD exchange rate (RX). The general form of the export equations in each group of manufactured wood products are:

$$X_t^w = \beta_1^{xw} + \beta_2^{xw} IPI_t + \beta_3^{xw} PX_t^w/RX_t + \varepsilon_t^{xw} \qquad (3\text{-}16)$$

$$X_t^f = \beta_1^{xf} + \beta_2^{xf} IPI_t + \beta_3^{xf} PX_t^f/RX_t + \varepsilon_t^{xf} \quad (3\text{-}17)$$

$$X_t^z = \beta_1^{xz} + \beta_2^{xz} IPI_t + \beta_3^{xz} PX_t^z/RX_t + \varepsilon_t^{xz} \quad (3\text{-}18)$$

Imports (M)

Data for 2014 indicates that imports of wood and manufactured wood products of the wood, furniture, and pulp & paper industries, as well as that of unprocessed wood into Colombia were valued at USD 246.6 million, with the biggest provider being Chile with 30.4% of market share, followed by China and Ecuador with 20% each (Ministerio del Medio Ambiente y Desarrollo Sostenible & ONF Andina, 2015). Given that Colombia has a large untapped capacity to produce unprocessed wood and manufactured wood products at competitive prices (Martínez Cortés, 2017a), one of the motivations for the CFSM is to provide analytical advice on a sustainable development plan for capacity expansion, which in turn will lower imports and meet the increase in demand stemming from a growing population and higher income levels.

Import equations for each group of manufactured wood products include the usual explanatory variables that determine it: the consumption expenditure, together with the relative price of consumption with respect to imports, and the capacity utilization rate for each industry.

$$M_t^w = \beta_1^{mw} + \beta_2^{mw} C_t^w + \beta_3^{mw} PC_t^w/PM_t^w + \beta_4^{mw} CUR_t^w + \varepsilon_t^{mw} \quad (3\text{-}19)$$

$$M_t^f = \beta_1^{mf} + \beta_2^{mf} C_t^f + \beta_3^{mf} PC_t^f/PM_t^f + \beta_4^{mf} CUR_t^f + \varepsilon_t^{mf} \quad (3\text{-}20)$$

$$M_t^z = \beta_1^{mz} + \beta_2^{mz} C_t^z + \beta_3^{mz} PC_t^z/PM_t^z + \beta_4^{mz} CUR_t^z + \varepsilon_t^{mz} \quad (3\text{-}21)$$

Here, C is the consumption of products of the wood (w), furniture (f) and pulp & paper (z) industries derived from consumption equations 3-13, 3-14 and 3-15, respectively; PC is the price of consumption; PM is the price of imports; and CUR is the capacity utilization rate for each of the three industries considered.

3.2.1.2.3 Prices of C, X and M

The prices in the MWM are calculated based on the assumption that domestic goods and foreign goods are not perfect substitutes, and as such, different markets of the same manufactured wood products will be characterized by different prices. Therefore, the MWM does not calculate one prevailing price for all demand components (consumption, exports, and imports) but it presents a separate price equation for each component, introducing thus three price equations for each of the three manufactured wood products groups considered. This approach is based on increasing literature that shows the realistic nature of cross border prices, which do not necessarily behave according to the Law of One Price economic principle. Some of the factors for this deviation are trade frictions (tariffs), transportation costs (from point of origin to point of export), and differences in quality between domestic and foreign products, to name a few.

In addition to the above assumption, the equations for calculating the demand prices also consider the rigidity of prices, acknowledging that, in the short run, industry prices are reluctant to adjust to changes in other economic factors such as output and demand, among others. To account for the reality of price responsiveness, the explanatory variables for each price equation also include lagged prices, a method widely established in forecast models of central banks, and also applied in (Kant et al., 1996).

Consumption Price (PC)

The main determinants of the current price of consumption for each period are the total available supply for each group of manufactured wood products, and as explained above, the closing price of the preceding time period. The price equations for consumption for each manufactured products industry is therefore:

$$PC_t^w = \beta_1^{pcw} + \beta_2^{pcw} S_t^w + \beta_3^{pcw} PC_{t-1}^w + \varepsilon_t^{pcw} \qquad (3 - 22)$$

$$PC_t^f = \beta_1^{pcf} + \beta_2^{pcf} S_t^w + \beta_3^{pcf} PC_{t-1}^f + \varepsilon_t^{pcf} \qquad (3 - 23)$$

$$PC_t^z = \beta_1^{pcz} + \beta_2^{pcz} S_t^z + \beta_3^{pcz} PC_{t-1}^z + \varepsilon_t^{pcz} \qquad (3 - 24)$$

PC_t is the current price of consumption, PC_{t-1} is the lagged price of consumption and S_t is the current Supply (Production) from the equations 3-10 to 3-12, respectively.

Exports Price (PX)

Kant et al (1996) modelled the export price using as determining factors for each period the previous period export prices (lagged prices), the exchange rate for each country where the products are exported, and each country's wholesale price index (WPI) for the same time period, using US data.

As with exports, a better choice for determining the price of exports should include as explanatory variables the World Exports Price Index (WEPI) for each of the products considered and Colombia's USD exchange rate, as well as the lagged price of exports (PX_{t-1}) for each of the manufactured wood products exported. The price equations for exports for each manufacturing product industry are therefore:

$$PX_t^w = \beta_1^{pxw} + \beta_2^{pxw} PX_{t-1}^w + \beta_3^{pxw} RX_t + \beta_4^{pxw} WEPI_t^w + \varepsilon_t^{pxw} \qquad (3\text{-}25)$$

$$PX_t^w = \beta_1^{pxw} + \beta_2^{pxw} PX_{t-1}^w + \beta_3^{pxw} RX_t + \beta_4^{pxw} WEPI_t^f + \varepsilon_t^{pxw} \qquad (3\text{-}26)$$

$$PX_t^z = \beta_1^{pxz} + \beta_2^{pxz} PX_{t-1}^z + \beta_3^{pxz} RX_t + \beta_4^{pxz} WEPI_t^z + \varepsilon_t^{pxz} \qquad (3\text{-}27)$$

Imports Price (PM)

Similarly, to the variables used by Kant et al (1996), the price of imports for each group of manufactured wood products depend mainly on the USD exchange rate for Colombia, the previous period's import price, as well as the competing domestic consumption price for the same product (PC), derived in equations 3-22, 3-23 and 3-24, respectively. The price equations for imports for each group of manufactured wood products are therefore:

$$PM_t^w = \beta_1^{pmw} + \beta_2^{pmw} PM_{t-1}^w + \beta_3^{pmw} PC_t^w/PC_{t-1}^w + \beta_4^{pmw} RX_t + \varepsilon_t^{pmw} \qquad (3\text{-}28)$$

$$PM_t^f = \beta_1^{pmf} + \beta_2^{pmf} PM_{t-1}^f + \beta_3^{pmf} PC_t^f / PC_{t-1}^f + \beta_4^{pmf} RX_t + \varepsilon_t^{pmf} \qquad (3\text{-}29)$$

$$PM_t^z = \beta_1^{pmz} + \beta_2^{pmz} PM_{t-1}^z + \beta_3^{pmz} PC_t^z/PC_{t-1}^z + \beta_4^{pmz} RX_t + \varepsilon_t^{pmz} \qquad (3\text{-}30)$$

Where PC_{t-1} is the lagged price of consumption for each group of manufactured wood products.

3.2.2 Structure of the Unprocessed Wood Market (sub)model (UWM)

The UWM is an extension of the model developed by Kant et al. (1996), which only included the manufactured wood products of the forest industry of the Canadian forest product sector. The UWM comprises two partial equilibrium models for the unprocessed wood[9] market, one for the unprocessed wood used for firewood, and one for the unprocessed wood used for both wood as an input for industrial uses in the manufactured wood products industry, and wood for final rural consumption other than firewood, as previously defined.

Each partial equilibrium model is a system of simultaneous linear equations comprising one identity for the market clearing condition – MCC, two summation identities (for supply and demand) and eight behavioral equations that explain supply by source (forest plantations and natural forest), as well as consumption, exports and imports, and their respective prices. In addition, the model includes four auxiliary summation identities for calculating the volume available for supply from forest plantations, and to split the supply of wood products from the furniture industry into wooden and non-wood furniture. Finally, five summation identities and one MCC identity for the aggregated market of the unprocessed wood complete the UWM.

In the market of unprocessed wood, supply (total production) is the sum of supply from Colombia´s commercial forest plantations, natural forest and agroforestry systems, and trees outside the forests. Due to increasing interest in forest plantation development by Colombia´s government, during Phase I, the CFSM is only run with the equations with detailed specification of wood

[9] In Colombia unprocessed wood is the name given to several categories of wood removals from the forest ecosystems (including trees outside forests) with or without bark: wood in its round form (called roundwood) or split, roughly squared or in other form (e.g. branches) and wood that is roughly shaped or pointed, independent of their use (firewood and wood for charcoal, industrial including wood for forest bioenergy industries, etc.). In Colombia, the unprocessed wood market is also known as the wood market. Wood for charcoal production is negligible and if any, it is added to firewood in the CFSM. Other sources of wood fibre (such as recycling of wood and manufactured wood products) are considered under the category of unprocessed wood in Phase I of the CFSM, bearing in mind that recycling is another source that should be accounted for, due to potential effect on the unprocessed wood market. A complete development of the recycling of wood fibre feature of the CFSM is only foreseeable in Phase II.

supply from commercial forest plantations[10]. Wood supply from natural forests is included in Phase I either as a basic equation which depends only on the price of supply, or as a lump-sum estimation based on trends in the historical supply of wood from this source as per the national wood consumption balances[11]. Wood supply from agroforestry systems is modelled as being part of supply from commercial forest plantations, and supply from trees outside forest is modelled as being part of supply from commercial forest plantations and from natural forests. The complete specification for the supply from the sources outside of commercial forest plantations will be addressed in Phase II of the CFSM.

Tables 3-4 and 3-5 present a summary of the 16 behavioral equations and 13 identities of the UWM and their variables, respectively, followed by the economic justifications necessary for the selection of each variable. Conversion factors used in the UWM are presented in Appendix 3-1.

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[10] Other types of forest plantations exist in Colombia (e.g. protective forest plantations), but they are not used for commercial wood production. Non-commercial forest plantations are set with other objectives that are more likely to be modelled under forest ecosystems services in Phase II of the CFSM.

[11] Supply of wood from natural forests has been declining in Colombia. In 2013, wood from this source accounted for up to 50% of the national wood output for industrial use and final consumption without firewood (Martínez Cortés, 2017a). Although there have been some national initiatives that have been promoting agroforestry systems in Colombia, supply of wood from this source, plus supply of wood from trees outside the forest in Colombia is still considered negligible. In the software application for running the CFSM, there is an option to run the model considering the supply from natural forests as a lump-sum or as coming from an estimated equation.

Table 3-4 Theoretical Equations and Identities for the UWM

Identity or equation number	Identity or Equation name	Identity or General Equation
3-31	Market Clearing Condition for the unprocessed wood-rw	$ST_t^{rw} = DT_t^{rw}$
3-32	Total Supply (Production) of unprocessed wood	$ST_t^{rw} = S_t^{MWrw} + S_t^{FWrw}$
3-33	Total Demand of unprocessed wood	$DT_t^{rw} = CT_t^{rw} + XT_t^{rw} - MT_t^{rw}$
3-34	Total Consumption of unprocessed wood	$CT_t^{rw} = C_t^{MWrw} + C_t^{FWrw}$
3-35	Total Exports of unprocessed wood	$XT_t^{rw} = X_t^{MWrw} + X_t^{FWrw}$
3-36	Total Imports of unprocessed wood	$MT_t^{rw} = M_t^{MWrw} + M_t^{FWrw}$
3-37	Market Clearing Condition of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$S_t^{MWrw} = C_t^{MWrw} + X_t^{MWrw} - M_t^{MWrw}$ (i.e. $S_t^{MWrw} = D_t^{MWrw}$)
3-38	Market Clearing Condition of unprocessed wood for firewood	$S_t^{FWrw} = C_t^{FWrw} + X_t^{FWrw} - M_t^{FWrw}$ (i.e. $S_t^{FWrw} = D_t^{FWrw}$)
3-39	Supply (Production) of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$S_t^{MWrw} = S_t^{MWfprw} + S_t^{MWnfrw} + S_t^{MWastorw}$
3-40	Supply (Production) of unprocessed wood for firewood (including wood for producing charcoal)	$S_t^{FWrw} = S_t^{FWnfrw} + S_t^{FWastorw} + S_t^{FWfprw}$
3-41	Supply (Production) of unprocessed wood for the manufactured wood products industry & final consumption other than firewood from Forest Plantations	$S_t^{MWfprw} = \beta_1^{sMWfprw} + \beta_2^{sMWfprw} VAST_t^{MWfprw} + \beta_3^{sMWfprw} PS_t^{MWrw} + \beta_4^{sMWfprw} L_t^{MWfprw} + \beta_5^{sMWfprw} K_t^{MWfprw} + \beta_6^{sMWfprw} GEN^{MWfprw} + \varepsilon_t^{sMWfprw}$
3-42	Supply (Production) of unprocessed wood for the manufactured wood products industry & final consumption other than firewood from natural forest	$S_t^{MWnfrw} = \beta_1^{sMWnfrw} + \beta_2^{sMWnfrw} VAST_t^{MWnfrw} + \beta_3^{sMWnfrw} PS_t^{MWrw} + \beta_4^{sMWnfrw} L_t^{MWnfrw} + \beta_5^{sMWnfrw} K_t^{MWnfrw} + \beta_6^{sMWnfrw} GEN_t^{MWnfrw} + \varepsilon_t^{sMWnfrw}$
3-43	Supply (Production) of unprocessed wood for firewood from natural forest	$S_t^{FWnfrw} = \beta_1^{sFWnfrw} + \beta_2^{sFWnfrw} VAST_t^{FWnfrw} + \beta_3^{sFWnfrw} PS_t^{FWrw} + \beta_4^{sFWnfrw} GEN_t^{FWnfrw} + \varepsilon_t^{sFWnfrw}$
3-44	Total Volume of Available Stock for Supply of unprocessed wood for the manufactured wood products industry & final consumption other than firewood, at the beginning of year t, in all stands of commercial forest plantations	$VAST_t^{MWfprw} = VAST_{t-1}^{MWfprw} + VG_{t-1}^{MWfprw} - VH_{t-1}^{MWfprw}$
3-45	Net growth (in volume) in year t-1 (Growth – Losses due to mortality and other events) in all stands of forest plantations	$VG_{t-1}^{MWfprw} = VAS_{t-1}^{MWfprw} – VAS_{t-2}^{MWfprw}$
3-46	Harvested Volume of unprocessed wood for the manufactured wood products industry & final consumption other than firewood, in year t-1 in all stands of commercial forest plantations	$VH_{t-1}^{MWfprw} = VH_{t-1}^{MWrw} - VH_{t-1}^{MWnfrw}$
3-47	Harvested Volume of unprocessed wood for the manufactured wood products industry & final consumption other than firewood, in year t-1 from all sources	$VH_{t-1}^{MWrw} = QEUW_{t-1}^{MWrw} / PEUW_{t-1}^{MWrw}$
3-48	Consumption of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$C_t^{MWrw} = \beta_1^{cMWrw} + \beta_2^{cMWrw} S_t^{w} + \beta_3^{cMWrw} S_t^{f} + \beta_4^{cMWrw} S_t^{z} + \beta_5^{cMWrw} PC_t^{MWrw} + \varepsilon_t^{cMWrw}$
3-49	Consumption of unprocessed wood for firewood	$C_t^{FWrw} = \beta_1^{cFWrw} + \beta_2^{cFWrw} U_t + \beta_3^{cFWrw} PC_t^{FWrw} + \beta_4^{cFWrw} NR_t + \beta_5^{cFWrw} W_t + \beta_6^{cFWrw} Y_t + \beta_7^{cFWrw} i_t + \beta_8^{cFWrw} GEO_t + \varepsilon_t^{cFWrw}$
3-50	Exports of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$X_t^{MWrw} = \beta_1^{xMWrw} + \beta_2^{xMWrw} IPI_t + \beta_3^{xMWrw} PX_t^{MWrw}/RX_t + \varepsilon^{xMWrw}$
3-51	Exports of unprocessed wood for firewood	$X_t^{FWrw} = \beta_1^{xFWrw} + \beta_2^{xFWrw} IPI_t + \beta_3^{xFWrw} PX_t^{FWrw}/RX_t + \varepsilon^{xFWrw}$
3-52	Imports of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$M_t^{MWrw} = \beta_1^{mMWrw} + \beta_2^{mMWrw} C_t^{MWrw} + \beta_3^{mMWrw} PC_t^{MWrw} / PM_t^{MWrw} + \beta_4^{mMWrw} CUR_t^{MW} + \beta_5^{mMWrw} VAST_t^{MWfprw} + \varepsilon^{mMWrw}$
3-53	Imports of unprocessed wood for firewood	$M_t^{FWrw} = \beta_1^{mFWrw} + \beta_2^{mFWrw} C_t^{FWrw} + \beta_3^{mFWrw} PC_t^{FWrw} / PM_t^{FWrw} + \varepsilon^{mFWrw}$
3-54	Consumption price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$PC_t^{MWrw} = \beta_1^{pcMWrw} + \beta_2^{pcMWrw} S_t^{MWrw} + \beta_3^{pcMWrw} PC_{t-1}^{MWrw} + \varepsilon_t^{pcMWrw}$
3-55	Consumption price of unprocessed wood for firewood	$PC_t^{FWrw} = \beta_1^{pcFWrw} + \beta_2^{pcFWrw} S_t^{FWrw} + \beta_3^{pcFWrw} PC_{t-1}^{FWrw} + \varepsilon_t^{pcFWrw}$
3-56	Export price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$PX_t^{MWrw} = \beta_1^{pxMWrw} + \beta_2^{pxMWrw} PX_{t-1}^{MWw} + \beta_3^{pxMWrw} RX_t + \beta_4^{pxMWrw} WEPI_t^{w} + \varepsilon_t^{pxMWrw}$
3-57	Export price of unprocessed wood for firewood	$PX_t^{FWrw} = \beta_1^{pxFWrw} + \beta_2^{pxFWrw} PX_{t-1}^{FWrw} + \beta_3^{pxFWrw} RX_t + \beta_4^{pxFWrw} WEPI_t^{w} + \varepsilon_t^{pxFWrw}$
3-58	Import price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$PM_t^{MWrw} = \beta_1^{pmMWrw} + \beta_2^{pmMWrw} PM_{t-1}^{MWrw} + \beta_3^{pmMWrw} PC_t^{MWrw} / PC_{t-1}^{MWrw} + \beta_4^{pmMWrw} RX_t + \varepsilon^{pmMWrw}$
3-59	Import price of unprocessed wood for firewood	$PM_t^{FWrw} = \beta_1^{pmFWrw} + \beta_2^{pmFWrw} PM_{t-1}^{FWrw} + \beta_3^{pmFWrw} PC_t^{FWrw} / PC_{t-1}^{FWrw} + \beta_4^{pmFWrw} RX_t + \varepsilon^{pmFWrw}$
Variables, and paramters, are to be read as follows:	**$PC_t^{MWrw} = \beta_1^{pcMWrw} + \beta_2^{pcMWrw} S_t^{MWrw} + \beta_3^{pcMWrw} PC_{t-1}^{MWrw} + \varepsilon_t^{pcMWrw}$** **(Equation 3 - 54)**	
	PC_t^{MWrw} : Consumption price of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, at time t β_1^{pcMWrw} , β_2^{pcMWrw} , β_3^{pcMWrw} : Firts (Independent), second and third population parameter of the equation of consumption price of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, repectively. S_t^{MWrw} : Supply (production) of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, at time t PC_{t-1}^{MWrw} : Consumption price of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, at time t-1 (i.e. lagged 1 period) ε_t^{pcMWrw} : Disturbance stochastic term of the equation of consumption price of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, at time t	

Table 3-5 Variables used for theoretical equations of the UWM

Variables	Description
C	Consumption
CT	Total consumption
CUR	Capacity utilization rate of the manufacrtured wood products industry
D	Demand
DT	Total demand
GEN	Control variable for costs of harvesting wood not captured by other harvested-related variables in the equation
GEO	Geographic location
i	Inflation
IPI	World's Industrial Production Index
K	Capital
L	Labor
M	Imports
MT	Total imports
NR	Total Rural Population
PC	Price of consumption
PEUW	Equilibrium Price in the Market of Unprocessed Wood for the manufactured wood products industry
PM	Price of imports
PS	Price of supply
PX	Price of exports
QEUW	Equilibrium Quantity in the Market of Unprocessed Wood for the manufactured wood products industry
RX	Exchange rate
S	Supply
ST	Total Supply
U	Unemployment
VAS	Total Volume of available stock of unprocessed wood for Supply at the end of a year as provides by the SCRPFC
VAST	Total Volume of available stock of unprocessed wood for Supply at the beginning of a year
VG	Net growth (in wood volume) in a year (Growth – Losses due to mortality and other events)
VH	Harvested Volume of unprocessed wood
W	Wealth
WEPI	World Exports price Index
X	Exports
XT	Total exports
Y	Total income

Superscripts	Description
cMWrw	of the equation of consumption of unprocessed wood for the manufactured wood products industry & final consumption other than firewood
cFWrw	of the equation of consumption of unprocessed wood for firewood
f	furniture industry
FWastorw	unprocessed wood for firewood from agroforestry systems and trees outside the forest
FWfprw	unprocessed wood for firewood from forest plantations
FWnfrw	unprocessed wood for firewood from the natural forest
FWrw	unprocessed wood for firewood
mFWrw	of the equation of imports of unprocessed wood for firewood
MWastorw	unprocessed wood for the manufactured wood products industry & final consumption other than firewood from agroforestry systems and trees outside the forest
MWfprw	unprocessed wood for the manufactured wood products industry & final consumption other than firewood from forest plantations
MWnfrw	unprocessed wood for the manufactured wood products industry & final consumption other than firewood from natural forest
MWrw	unprocessed wood for the manufactured wood products industry & final consumption other than firewood
mMWrw	of the equation of imports of unprocessed wood for the manufactured wood products industry & final consumption other than firewood
pcFWrw	of the equation of consumption price of unprocessed wood for consumption as firewood
pcMWrw	of the equation of consumption price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood
pmFWrw	of the equation of imports price of unprocessed wood for consumption as firewood
pmMWrw	of the equation of imports price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood
pxFWrw	of the equation of exports price of unprocessed wood for consumption as firewood
pxMWrw	of the equation of exports price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood
rw	unprocessed wood (or raw wood)
sFWnfrw	of the equation of supply of unprocessed wood for firewood from natural forest
sMWfprw	of the equation of supply of unprocessed wood for the manufactured wood products industry & final consumption other than firewood from forest plantations
sMWnfrw	of the equation of exports price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood natural forest
xFWrw	of the equation of exports of unprocessed wood for firewood
xMWrw	of the equation of exports of unprocessed wood for the manufactured wood products industry & final consumption other than firewood
w	wood industry
z	pulp (Zellstoff in German) and paper industry

Subscripts	Description
t	time

3.2.2.1 General identities

The Colombian unprocessed wood (UW) market is the aggregate of two (sub)markets: unprocessed wood for industrial use & final rural consumption and unprocessed wood for firewood. As in the MWM, it is assumed that each sub(market) and its aggregate market considered in the UWM can be modelled as a system of simultaneous linear equations using the theoretical framework of competitive markets. Therefore, summation and clearing condition identities hold in each (sub)market and the aggregated market. Also, as in the MWM, market clearing condition (MCC) requires that the total (T) supply (S) for the aggregated market and (sub)markets modelled, is equal to its total demand (D) (i.e., consumption plus exports, minus the imports), respectively. Similarly, the totals for each economic variable of interest in the aggregated market: supply, consumption (C), exports (X) and imports (M) are given by a linear sum of the subtotals for each (sub)market considered.

Both MCC and summation identities for the aggregate market and the (sub)markets can be written as follows:

$$ST_t^{rw} = DT_t^{rw} \tag{3-31}$$

$$ST_t^{rw} = S_t^{MWrw} + S_t^{FWrw} \tag{3-32}$$

$$DT_t^{rw} = CT_t^{rw} + XT_t^{rw} - MT_t^{rw} \tag{3-33}$$

$$CT_t^{rw} = C_t^{MWrw} + C_t^{FWrw} \tag{3-34}$$

$$XT_t^{rw} = X_t^{MWrw} + X_t^{FWrw} \tag{3-35}$$

$$MT_t^{rw} = M_t^{MWrw} + M_t^{FWrw} \tag{3-36}$$

$$S_t^{MWrw} = C_t^{MWrw} + X_t^{MWrw} - M_t^{MWrw} \quad (\text{i.e., } S_t^{MWrw} = D_t^{MWrw}) \tag{3-37}$$

$$S_t^{FWrw} = C_t^{FWrw} + X_t^{FWrw} - M_t^{FWrw} \quad (\text{i.e., } S_t^{FWrw} = D_t^{FWrw}) \tag{3-38}$$

Where: rw is unprocessed (raw) wood, MWrw - unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, and FWrw - unprocessed wood for firewood.

3.2.2.2 Behavioral Equations and Auxiliary Summation Identities

3.2.2.2.1 Supply (production) of unprocessed wood

Regression equations using supply (production) as dependent variables are used to model each of two markets considered: unprocessed wood for industrial use & final rural consumption other than firewood, and unprocessed wood for firewood. Before presenting these equations, details on the supply of unprocessed wood by source are needed.

Supply of unprocessed wood by source (ecosystem) in Colombia

Unprocessed wood in Colombia is supplied from four different sources:

1) Natural forests (nf)
2) Commercial forest plantations (fp)
3) Agroforestry systems (as)
4) Trees outside forest (to)

Information retrieved from the little available data on the contribution of agroforestry systems and trees outside forests to the unprocessed wood market suggests that this contribution has a less share in the stock of wood, and therefore a minor significant impact on the total supply [12]. As such, these two sources are grouped (denominated as *asto*), and their joint impact in the supply is instead measured. Based on the assumption that all domestic supply of unprocessed wood comes only from the above sources[13], the total supply of unprocessed wood (S) for each (sub)market

[12] Although there have been some national initiatives that have been promoting agroforestry systems in Colombia, supply of wood from this source, plus supply of wood from trees outside the forest in Colombia is still considered negligible.

[13]Other sources of wood fiber (such as recycling of wood and manufactured-wood products) that could affect the market of unprocessed wood are not considered in Phase I of the CFSM. A complete development of the recycling of wood fibers as a feature of the CFSM is foreseeable only in Phase II.

Regarding domestic supply, figures for 1995, 2013 and 2016 indicate that unprocessed wood supplied for the Colombian manufactured wood products industry is a mix from wood coming from forest plantations and natural forests, and that supply of wood for industrial use from natural forests has been declining since 1995, when its share was 75%, to 50% in 2013 (Martínez Cortés, 2017a). In 2016, wood for pulp industry was provided entirely from unprocessed wood from commercial forest plantations; wood-based panels supply comprises wood from commercial forest plantations and negligible amounts of sawndust and other sawnwood industry residues of wood from natural forests. In turn, the supplying of unprocessed wood for the sawnwood industry was made up by a mix of both sources: natural forests and commercial forest plantations, with an increasing share of wood from the latter during the past years (Martinez-Cortes et al., 2018a). Colombia's 2017- installed-production capacity of the pulp, wood-based panels, and sawnwood industries was estimated at 4.8 Mm^3rsc/year (1.0 Mm^3rsc/year for pulp, 0.8 Mm^3rsc/year for panels considered, at the beginning of any year t[14] in monetary values, will be the sum of the supply from each of the sources (ecosystem) as follows:

$$S_t^{MWrw} = S_t^{MWfprw} + S_t^{MWnfrw} + S_t^{MWastorw} \quad (3\text{-}39)$$

$$S_t^{FWrw} = S_t^{FWnfrw} + S_t^{FWastorw} + S_t^{FWfprw} \quad (3\text{-}40)$$

Where MWrw is unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, MWfprw is unprocessed wood from commercial forest plantations for the manufactured wood products industry & final rural consumption other than firewood, MWnfrw - unprocessed wood from the natural forest for the manufactured wood products industry & final rural consumption other than firewood, MWastorw - unprocessed wood from agroforestry systems and trees outside the forest for the manufactured wood products industry & final rural consumption other than firewood, FWrw is unprocessed wood for firewood, FWnfrw - unprocessed wood from the natural forest for firewood, FWastorw - unprocessed wood from agroforestry systems, trees outside the forest for firewood, and FWfprw - unprocessed wood from commercial forest plantations for firewood.

Although identity 39 and 40 include separate supply from agroforestry systems and trees outside forest, Colombia has no separate data for the supply coming from these two sources. Instead, data for these supplies are part of the data for supply from commercial forest plantations (for the agroforestry system cases) and from natural & commercial forest plantation (for trees outside forest). Consequently, in the UMW of the CFSM Phase I, $S_t^{MWastorw}$ and $S_t^{FWastorw}$ are not fully specified (i.e., equations are not included) and are assumed to be part of the other supplies from natural forest and commercial forest plantations.

In addition, during Phase I, it is assumed that supply for firewood and for final rural consumption other than firewood from commercial forest plantations is zero. Hence, S_t^{FWnfrw} is not specified

and 3.0 Mm^3rsc/year for sawnwood (Martinez-Cortes et al., 2018a); production capacity refers to the equivalent cubic meters of roundwood excluding bark needed to produce an amount of manufactured wood products in the industrial plants working 24 hours.

[14] Supply is calculated at the beginning of each year and not at the end, in order to provide a realistic description of what happens in reality in this market, which is that quotas for harvesting are determined at the beginning of each calendar year by managers.

and S_t^{MWfprw} is assumed to be only unprocessed wood for manufactured wood products industry consumed domestically and exported[15]. This follows the consensus in Colombia that almost the entire demand of these two uses is met by the supply of wood from natural forests[16].

Finally, for the market of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, several types of wood are commercialized in Colombia (e.g. pulpwood, sawlogs, logs for poles and other roundwood uses, etc.). However, in Phase I (due to data constrains) unprocessed wood for the above use is considered a general commodity independently of the source or type of wood[17].

Equation for St^{MWfprw}

The behavior equation for S_t^{MWfprw} (which includes exported unprocessed wood) is micro founded. Modelling this variable requires more than the assumption that volume of wood available for supply – i.e., for harvesting in commercial forest plantations ($VAST^{fp}$) is equal to the supply of unprocessed wood from this source (S_t^{MWfprw}). This limitation comes from the fact that there is a considerable time lag between (re)forestation of a stand and its maturity (its availability for use), therefore the supply equation for the unprocessed wood needs to capture the effect that capacity has on the supply curve, as well as the costs related with harvesting.

In general function form, the supply of unprocessed wood coming from the commercial forest plantation ecosystem at year t will be:

[15] Colombia exports small quantities of unprocessed wood from commercial forest plantations of teak (*Tectona grandis*) for industrial uses mainly to India. Exporting unprocessed wood from natural forest is forbidden by law in this country.

[16] In the Colombian market of unprocessed wood, wood for final consumption in fences, rural construction, other rural uses different to firewood, and firewood, is supplied almost entirely form the natural forest, with a minor supply from agroforestry systems and trees outside forests. Future developments of the CFSM are projected to include behavioral equations, in order to explain the final demand for unprocessed wood for fences, rural construction, and other uses different to firewood (mainly agricultural related).

[17] The goal for future developments of the CFSM (when data becomes available) is to add more detail to the specification of the unprocessed wood market, as the differentiation between the price of wood for pulp & panels and that of wood for sawnwood coming from commercial forest plantations has started only in the recent years. It might also be possible to include more detail depending on the sourcing of unprocessed wood if data becomes available.

$$S_t^{MWfprw} = f\,(VAST_t^{fp}, COH_t^{fp})$$

Where $VAST_t$ is the stock available for supply at the beginning of year t, and COH_t is the cost of harvesting for the logging industry of forest plantations, which captures the general determinants of supply (labor, capital and price) and also explains other costs (e.g. transportation, licenses, etc.), important in the unprocessed wood market. The linearity assumptions in the MWM extends to the unprocessed wood supply, as follows:

$$S_t^{MWfprw} = \beta_1^{sMWfprw} + \beta_2^{sMWfprw} VAST_t^{MWfprw} + \beta_3^{sMWfprw} PS_t^{MWrw} + \beta_4^{sMWfprw} L_t^{MWfprw} + \beta_5^{sMWfprw} K_t^{MWfprw} + \beta_6^{sMWfprw} GEN_t^{MWfprw} + \varepsilon_t^{sMWfprw} \quad (3\text{-}41)$$

Here, PS^{MWrw} is the price of supply of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, L_t^{MWfprw} and K_t^{MWfprw} are labor and capital for the logging industry of commercial forest plantations, and GEN captures other costs of harvesting and those not captured by the L_t^{MWfprw} and K_t^{MWfprw} variables.

Equations for S_t^{MWnfrw} and S_t^{FWnfrw}

A similar approach for the S_t^{MWfprw} was chosen to define the general equations for both the supply of unprocessed wood from natural forest for the manufactured wood products industry & final rural consumption other than firewood (Equation 3-42), and for the supply of unprocessed wood from natural forest for firewood (3-43).

$$S_t^{MWnfrw} = \beta_1^{sMWnfrw} + \beta_2^{sMWnfrw} VAST_t^{MWnfrw} + \beta_3^{sMWnfrw} PS_t^{MWrw} + \beta_4^{sMWnfrw} L_t^{MWnfrw} + \beta_5^{sMWnfrw} K_t^{MWnfrw} + \beta_6^{sMWnfrw} GEN_t^{MWnfrw} + \varepsilon_t^{sMWnfrw} \quad (3\text{-}42)$$

$$S_t^{FWnfrw} = \beta_1^{sFWnfrw} + \beta_2^{sFWnfrw} VAST_t^{FWnfrw} + \beta_3^{sFWnfrw} PS_t^{FWrw} + \beta_4^{sFWnfrw} GEN_t^{FWnfrw} + \varepsilon_t^{sFWnfrw} \quad (3\text{-}43)$$

For equation (3-43), labor and capital are not included, as there is no formal logging industry for firewood in Colombia. Instead, people living in rural areas usually collect wood for own household consumption, such as cooking and heating. In this equation, GEN is a control variable for all costs of harvesting wood for firewood.

Alternatively to equations 3-42 and 3-43, the UWM in Phase I of the CFSM includes the option of using S_t^{MWnfrw} and S_t^{FWnfrw} as lump-sum estimations, as previously mentioned.

VAST by source (ecosystem) in the UWM

In the UWM, equations 3-41, 3-42 and 3-43 include as an explanatory variable the volume of wood available for supply – i.e., for harvesting (VAST) in the respective ecosystem from one period of time to another.

Forest dynamics literature has established that year-to-year[18] changes in VAST are the result of the following factors: the volume harvested during each year (VH), the increase in volume due to natural growth (ΔG), and decrease in volume due to mortality (ΔM). As a result, the total volume available for supply (VAST) at the beginning of year t, for each ecosystem J, can be captured by the following general-form identity:

$$VAST_t(J) = VAST_{t-1}(J) + \Delta G_{t-1}(J) - \Delta M_{t-1}(J) - VH_{t-1}(J) \qquad (3\text{-}43A)$$

Where J = {fp, nf, asto}, and $VAST_{t-1}(J)$ is the available stock for supply of unprocessed wood at the end of year t-2, which acts as an opening balance for the available stock for supply at the beginning of year t-1, in each ecosystem J, and $VH_{t-1}(J)$ is the volume harvested during year t-1 in each of the J ecosystems considered[19].

At this point it is necessary to explain in more detail the importance of the variables of equation 3-43A and how they are modelled into the CFSM Phase I.

Variables VH and VAST are two of the key forest sector policy variables in the CFSM. As explanatory variables, they can answer policy design questions, such as what would be the effect on the forest industry and forests markets if a policy for an expansion of commercial forest plantations is to be implemented. On the other direction, calculating VH and VAST based on market conditions of either the UW or MW markets, would provide helpful results on questions

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[18] For the purpose of the CFSM, the time period is chosen to be 1-year increments as most of growth and yield data for forest ecosystems is usually reported yearly. This choice is also consistent with the time frame for which economic data to be used for estimating the CFSM equations is reported for most of the variables (macro and sectoral variables) in Colombia.

[19] Although in Phase I the supply from agroforestry systems and trees outside forest (asto) is part of the supply from commercial forest plantations and natural forest, the calculation of VAST explained in this section provides the option to include this as a separate variable in Phase II.

like: a) what would happen to the sources of unprocessed wood and in the wood forest products markets if a policy to incentivize consumption or change patterns of trade is to implemented, and b) what would be needed in terms of supplying unprocessed wood (e.g. increasing of harvest rates in the natural forests and forest plantations and/or importing unprocessed wood) if a policy to expand the wood forest products industry is to be developed, among others.

The following two options for modelling VH and VAST are offered into the CFSM Phase I:

First, VH and VAST can be modelled as variables determined by the supply and demand of the manufactured wood products market and the exports of unprocessed wood. In this case, VH is determined endogenously in the CFSM (as explained later) and it enables the CFSM model to capture the effect that macroeconomic or sectoral shocks (for example changes in consumption patterns, or trade) in both, the manufactured wood products market and the unprocessed wood one, will have on the forest sector by affecting harvest rates VH, which in turn affect volume available for supply VAST.

Second, VH and VAST can be treated as exogenous variables (i.e., actual or potential commercial plantation area volume capacity) and used to forecast the supply and demand of the unprocessed wood market and, consequently, those of the manufactured wood products market. This would analyze the effect of different commercial forest plantation expansion plans on the sectoral variables (e.g. consumption or trade) in any or both of the UW and MW markets[20].

Coming back to identity 43A, due to the availability of data for Colombia for each of the ecosystems considered for this equation, the supply equations developed within the timeframe of this research are the ones capturing the volume of available stock for the supply of unprocessed wood originating from the commercial forest plantations.

Hence, the biological dynamics part of the UWM at Phase I includes only the wood volume availability equations pertaining to the commercial forest plantation ecosystem ($VAST^{fp}$), which is the same as $VAST_t^{MWfprw}$ given that only unprocessed wood for the manufactured wood products industry is sourced from this ecosystem. As explained in the previous sections, the growth and

[20] In future phases of the CFSM, once it is linked into a GE Model in the way explained in section 2.5, then effects on macroeconomic variables coming from shocks on both markets (UW and MW) can be estimated.

yield simulator called SCRPFC (whose theoretical structure is presented in Chapter 6) is used to simulate the biological dynamic part of the supply from the commercial forest plantations.

The following section presents the determination of VH for the manufactured wood products industry & final rural consumption other than firewood (VH^{MWrw}) and $VAST^{MWfprw}$, for each of the options of modelling VAST and VH mentioned above.

Determination of VH^{MWrw} and $VAST^{MWfprw}$

For the option where VH and VAST are variables determined by the supply and demand of the manufactured wood products market, VH is calculated using the forecasted equilibrium quantity (QEUW) and price (PEUW) in the unprocessed wood market (sub)model UWM for the MWrw (Eq. 3-37), derived in turn by the results on the manufactured wood products market as explained in section 3.2.1. The quantity supplied QEUW is in monetary values, and when divided by price PEUW, it represents the volume of unprocessed wood supplied (VUWS). This VUWS is exactly the VH^{MWrw} that must be harvested from all the sources of unprocessed wood. Once VH^{MWrw} is obtained, one can also easily derive $VAST^{MWfprw}$ by separating VH^{MWrw} into the share harvested in natural forests (VH^{MWnfrw}) and in commercial forest plantations (VH^{MWfprw}).

As an additional step for those interested, the latter can easily be used in summation identity 3-44 to estimate the required adjustments in VAST for the consecutive years.

$$VAST_t^{MWfprw} = VAST_{t-1}^{MWfprw} + VG_{t-1}^{MWfprw} - VH_{t-1}^{MWfprw} \qquad (3\text{-}44)$$

Where $VAST_t^{MWfprw}$ is the volume available for supply of unprocessed wood for the manufactured wood products industry at the beginning of year t. Here, VG_{t-1}^{MWfprw} is the growth in volume during year t-1 representing the year to year differences of available stock caused only by changes due to natural growth (ΔG) and mortality rate (ΔM) during year t-1 as captured by the SCRPFC, as follows:

$$VG_{t-1}^{MWfprw} = VAS_{t-1}^{MWfprw} - VAS_{t-2}^{MWfprw} \quad = \Delta G_{t-1} - \Delta M_{t-1}, \qquad (3\text{-}45)$$

where all variables represent volumes accumulated at the end of the respective year, VAS is the Volume of Wood Available for Supply as estimated by the SCRPFC, and VH^{MWfprw} is the volume share actually harvested from commercial forest plantations that is determined from summation identity 3-46.

$$VH_{t-1}^{MWfprw} = VH_{t-1}^{MWrw} - VH_{t-1}^{MWnfrw} \qquad (3\text{-}46)$$

As mentioned above, VH^{MWrw} is calculated from the division of the equilibrium prices and quantities in the unprocessed wood market (Equation 3-47)[21].

$$VH_{t-1}^{MWrw} = QEUW_{t-1}^{MWrw} / PEUW_{t-1}^{MWrw} \qquad (3\text{-}47)$$

For the option where $VAST^{MWfprw}$ is given for a year t, the process works in reverse order. In this direction, $VAST_t^{MWfprw}$ is an exogenous variable, and is entered in the unprocessed wood market on the supply side (equation 3-41), in order to derive the equilibrium prices PEUW and the equilibrium quantity QEUW in m^3. Once VH^{MWrw} is obtained as before, one can also easily calculate the share harvested in natural forests (VH^{MWnfrw}) and forest plantations (VH^{MWfprw}) needed to satisfy demand, using identity 3-44 for time t. PEUW are used as an input in the MW market, in order to calculate the equilibrium of this (sub)model, and as a consequence, the prices and quantities of consumption, exports and imports of the manufactured wood products market.

3.2.2.2.2 Demand for unprocessed wood

Consumption (C)

Consumption of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood (C_t^{MWrw}) is derived from the supply (production) of manufactured wood products of the wood, furniture and pulp and paper industries, and their prices of its consumption (PC_t^{MWrw}) by those industries. Hence, the regression equation for the consumption of unprocessed wood by the manufactured wood products industry (which enters as an input in the supply of each industry) can be written as follows:

[21] Notice that quantities of unprocessed wood imported and exported by Colombia are negligible.

$$C_t^{MWrw} = \beta_1^{cMWrw} + \beta_2^{cMWrw} S_t^{w} + \beta_3^{cMWrw} S_t^{f} + \beta_4^{cMWrw} S_t^{z} + \beta_5^{cMWrw} PC_t^{MWrw} + \varepsilon_t^{cMWrw}, \quad (3\text{-}48)$$

where S_t^w , S_t^f , S_t^z are the Supply (production) of the manufactured wood products of the wood, furniture and pulp and paper industries obtained from equations 3-10, 3-11 and 3-12 of the MWM, respectively.

On the other hand, for modelling consumption of unprocessed wood for firewood (C_t^{FWrw})[22] there is no consolidated data in Colombia on the driving forces behind this variable, as most of this market functions very informally and is almost entirely concentrated in rural areas. More specifically, there is no detailed data on the nature of market transactions for firewood used as final consumption. Instead, since the seventies, the National Accounts numbers have included some estimations for the market transactions of this product. For the UWM CFSM Phase I, equation 3-49 was defined, preliminarily, using a similar approach as that of the literature on consumption patterns for firewood in other developing countries -(FAO, 1994) and (Fox, 1984), which explains consumption of this product as dependable on levels of income (Y), wealth W (as a determinant of substituting firewood with other sources of energy), geographic location (GEO), and number of people per household (in this research rural population NR_t is instead used as unprocessed wood for firewood is almost entirely used in rural areas in Colombia). Other independent variables, such as inflation (i) and unemployment (U) were also added in this equation for consistency with the explanatory variables used to explain consumption in the MWM.

$$C_t^{FWrw} = \beta_1^{cFWrw} + \beta_2^{cFWrw} U_t + \beta_3^{cFWrw} PC_t^{FWrw} + \beta_4^{cFWrw} NR_t + \beta_5^{cFWrw} W_t + \beta_6^{cFWrw} Y_t + \beta_7^{cFWrw} i_t + \beta_8^{cFWrw} GEO_t + \varepsilon_t^{cFWrw} \quad (3\text{-}49)$$

In the near future, current efforts from different Colombian government sources are expected to provide more detailed information on the patterns of consumption of firewood in Colombia which might in turn require a future adjustment to the variables of equation 3-49[23].

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[22] As explained in the preceding sections, firewood in the CFSM includes wood used for charcoal production, which is negligible in Colombia.

[23] In meetings conducted in 2017, when looking for this data, Colombia´s Mining and Energy Planning Unit (UPME), the organization in charge of providing this data to the country, and collecting it for internal use in the preparation of

Exports (X)

Exports of unprocessed wood in Colombia is driven by the demand of foreign countries (importers) for unprocessed wood for final consumption as final use (in fences, rural construction, other rural uses different to firewood, and firewood), and for manufactured wood products, is modelled similar to exports of manufactured wood products in the MWM (section 3.2.1.2.2). Preliminary information about exports of unprocessed wood from Colombia suggests that it is driven solely by the manufacturing industries in the importing countries, mainly the wood industry, that no country dominates Colombia's exports of wood products, and that the pool of importing countries has and could change in the near future. Hence the exports equations can be written as follows:

$$X_t^{MWrw} = \beta_1^{xMWrw} + \beta_2^{xMWrw} IPI_t + \beta_3^{xMWrw} PX_t^{MWrw}/RX_t + \varepsilon^{xMWrw} \quad (3\text{-}50)$$

$$X_t^{FWrw} = \beta_1^{xFWrw} + \beta_2^{xFWrw} IsPI_t + \beta_3^{xFWrw} PX_t^{FWrw}/RX_t + \varepsilon^{xFWrw} \quad (3\text{-}51)$$

Here, MWrw and FWrw mean unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, and for firewood, respectively; IPI is the World's Industrial Production Index, PX is prices of exports and RX - Colombia's USD exchange rate.

Imports (M)

Theoretically, imports of unprocessed wood should be calculated as the sum of imports from unprocessed wood for final consumption as final use, and for the manufactured wood products industry, modelled similar to imports of manufactured wood products in the MWM (section 3.2.1.2.2). However, data on this market suggests that Colombia's imports of unprocessed wood are mainly driven by the consumption of unprocessed wood for the manufactured wood products. Hence, the independent variables for the equations of imports are the consumption of unprocessed wood for the manufactured wood products industry, the relative price of the consumption (PC) to the price of imports (PM), and the capacity utilization rate of the wood forest products industry (CUR). In addition to these variables, for equation of imports of unprocessed wood for manufactured wood products industry & final rural consumption other than firewood (equation

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the National Energy Balance, acknowledged several issues with the scarcity of available data for firewood (prices and consumption estimations). UPME and the National Department of Statistics (DANE) were, in 2017, putting in place a project to survey regionally firewood sources, its uses and prices, and were updating prices and consumption patterns for the National Energy Balance and the National Account System. It is foreseeable that adjustments to Equation 3-49 can be done during Phase II of the CFSM, when this data becomes available.

52), the volume available for supply could also be an indicator of any shortage of national unprocessed wood for the manufactured wood products industry. In CFSM Phase I, only VAST from forest plantations is considered to keep consistency with what was defined for equations of Supply in section 3.2.2.2.1. For equation of imports of unprocessed wood for firewood (equation 3-53) CUR and VAST are not considered main drivers and hence are excluded. The equation of imports of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, and that of imports for firewood are as follows:

$$M_t^{MWrw} = \beta_1^{mMWrw} + \beta_2^{mMWrw} C_t^{MWrw} + \beta_3^{mMWrw} PC_t^{MWrw} / PM_t^{MWrw} + \beta_4^{mMWrw} CUR_t + \beta_5^{mMWrw} VAST_t^{MWfprw} + \varepsilon^{mMWrw} \quad (3\text{-}52)$$

$$M_t^{FWrw} = \beta_1^{mFWrw} + \beta_2^{mFWrw} C_t^{FWrw} + \beta_3^{mFWrw} PC_t^{FWrw} / PM_t^{FWrw} + \varepsilon^{mFWrw} \quad (3\text{-}53)$$

Where MWrw and FWrw refers to unprocessed wood for manufactured wood products industry & final rural consumption other than firewood, and for firewood, respectively.

3.2.2.2.3 Prices of C, X and M

Following the same approach used in the MWM (sub)model for modelling prices, it is assumed that prices in the forest sector do not follow the Law of One Price principle, hence UWM includes not just one prevailing price for unprocessed wood but different prices in different markets such as the domestic, exports and imports markets. Also, UMW recognizes the sticky nature of the unprocessed wood prices through lagged prices.

Consumption Price (PC)

Both the current price of consumption and the lagged price of the preceding time period, as well as the current supply estimated with equations 3-39 and 3-40 are the explanatory variables for the equations of price of consumption as follows:

$$PC_t^{MWrw} = \beta_1^{pcMWrw} + \beta_2^{pcMWrw} S_t^{MWrw} + \beta_3^{pcMWrw} PC_{t-1}^{MWrw} + \varepsilon_t^{pcMWrw} \quad (3\text{-}54)$$

$$PC_t^{FWrw} = \beta_1^{pcFWrw} + \beta_2^{pcFWrw} S_t^{FWrw} + \beta_3^{pcFWrw} PC_{t-1}^{FWrw} + \varepsilon_t^{pcFWrw} \quad (3\text{-}55)$$

Where PC_t is the current price of consumption, PC_{t-1} is the lagged price of consumption and S_t is current Supply (Production) from the identities 3-39 and 3-40, which summarize the current supply obtained with equations 3-41 & 3-42, and 3-43 for the unprocessed wood for manufactured wood products industry & final rural consumption other than firewood (MWrw), and for firewood (FWrw), respectively.

Exports Price (PX)

Export price of unprocessed wood in the UWM is also modelled as in the MWM. Likewise, unprocessed wood exports are driven mainly by the wood industry, no country dominates Colombia's exports of unprocessed wood and the pool of countries where Colombia exports its unprocessed wood has and could change in the near future. Hence, the World Exports Price Index for manufactured wood products of the wood industry ($WEPI^w$), Colombia's USD exchange rate (RX) as well as the lagged price of exports (PX_{t-1}) of unprocessed wood exported are considered as explanatory variables in the equations of exports. The price equations for exports are therefore:

$$PX_t^{MWrw} = \beta_1^{pxMWrw} + \beta_2^{pxMWrw} PX_{t-1}^{MWw} + \beta_3^{pxMWrw} RX_t + \beta_4^{pxMWrw} WEPI_t^w + \varepsilon_t^{pxMWrw} \quad (3\text{-}56)$$

$$PX_t^{FWrw} = \beta_1^{pxFWrw} + \beta_2^{pxFWrw} PX_{t-1}^{FWrw} + \beta_3^{pxFWrw} RX_t + \beta_4^{pxFWrw} WEPI_t^w + \varepsilon_t^{pxFWrw} \quad (3\text{-}57)$$

Imports Price (PM)

Finally, and similar to Kant et al. (1996) and the MWM, the price of imports of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood (PM_t^{MWrw}) and for firewood (PM_t^{FWrw}) depend mainly on the USD exchange rate for Colombia (RX), the previous period's import price, as well as the competing domestic consumption price for the type of wood (PC), derived in equations 3-54 and 3-55, respectively. The price equations for imports for each type of unprocessed wood is therefore:

$$PM_t^{MWrw} = \beta_1^{pmMWrw} + \beta_2^{pmMWrw} PM_{t-1}^{MWrw} + \beta_3^{pmMWrw} PC_t^{MWrw} / PC_{t-1}^{MWrw} + \beta_4^{pmMWrw} RX_t + \varepsilon^{pmMWrw} \quad (3\text{-}58)$$

$$PM_t^{FWrw} = \beta_1^{pmFWrw} + \beta_2^{pmFWrw} PM_{t-1}^{FWrw} + \beta_3^{pmFWrw} PC_t^{FWrw} / PC_{t-1}^{FWrw} + \beta_4^{pmFWrw} RX_t + \varepsilon^{pmFWrw} \quad (3\text{-}59)$$

Where PM_{t-1} and PC_{t-1} are the lagged prices of imports and consumption, respectively, MWrw is unprocessed wood for manufacturing wood products industry & final rural consumption other than firewood, and FWrw is unprocessed wood for firewood.

Chapter 4
Calibration for Phase I of the CFSM (CFSM-I) - Data consolidation

4.1 Introduction

The feasibility of building an econometric model is directly linked to the availability of data that allows for the estimation of the theoretical equations (specification) of such a model. To estimate the model equations (the first step of the model calibration and validation process), the data must be consolidated. Data consolidation in this research included the collection of the historical data and information in order to support the estimations and assumptions of the CFSM, their organization for later use, obtaining raw data time series for their potential use in representing the variables of the theoretical equations presented in chapter 3, and their transformation as per the needs of the estimation process, to finally obtain the consolidated data time series used as input for the estimation process. The data consolidation process for the CFSM generated comprehensible information about the Colombian forest sector represented by long-term time series obtained for the first time, and documents and other pieces of sectoral information cataloguing on a database. The following sections and their appendices present these products.

4.2 Colombian Forest Sector Database (CFS-DB)

Extra efforts were made to carefully document the data consolidation process for the CFSM Phase I. The usual work with data for building a model was expanded to create a sector-specific database for the Forest Sector in Colombia, named CFS-DB, which was previously inexistent. The CFS-DB, presented in Appendix 4-1, includes all forest sector studies and data available as of December 2022, relevant for Phase I, and also applicable to Phase II. The CFS-DB holds around 1400 electronic files, several of them with valuable information yet to be published, which are organized in a virtual library with a corresponding description guide for easy access to the original electronic files.

The virtual library description guide is linked to three types of tables, part of the CFS-DB, containing data and documents for the data consolidation process of each CFSM equation presented in chapter 3: Raw data tables, Transformation tables and Consolidated data tables. A Raw data table for an equation contains, for each one of its variables, “all raw data” (i.e., as found in the original source); “all raw data” means each time series that was identified, before or during the process of estimation, as a potential candidate for capturing a particular variable of the theoretical equation, independent of whether it was used or not during the estimation process. A Transformation table, for an equation, comprises a detailed map of all the transformations needed to obtain the consolidated data for each of its variables (summarized later in section 4.3), starting with the raw data chosen from the different options of the potential time series organized in the corresponding Raw data table. A consolidated data table for an equation contains, for each one of its variables, only the time series that were actually used in any of the tries of estimation (it summarizes all the time series used for all variables). The tables are interlinked, making it easy for users to navigate from the consolidated data backwards to the raw data and its corresponding original source (i.e., the electronic file in the virtual library), and vice versa. Specific details on how to navigate the tables and the virtual library are provided in the Appendix 4-1.

The final purpose of the CFS-DB was to organize the forest and economic data and information, useful for the Colombian forest sector economic modeling, in order for it to be used in the development of the first version of the CFSM Phase I (CFSM-I), and in future work on the CFSM (model maintenance and development –e.g. Phase II-), as well as to make them available to other modelers.

The database proved to be instrumental in the statistical estimation of CFSM I, whose *final estimated equations* are presented in Chapter 5. A very common practice for econometric models is that the estimation of one or more of their equations requires several tries before obtaining an estimated equation that can be deemed a final estimated equation (i.e., appropriate to be part of the model). In econometric models based on linear equations, this process of several tries might be needed due to the apparent violation of some assumptions of the lineal regression model (e.g. presence of multicollinearity, heteroscedasticity and serial correlation), alternative specifications, coefficients that were statistically non-significant, or did not have the expected correct sign as per the economic theory. The problematic variables had to be further explored (e.g. by consolidating additional data, considering other variables that could capture the same factor, or documenting the historic factors that explained the discrepancies). During this process for the CFSM, the Data tables (consolidated and raw) and Transformation tables played an important facilitator’s role to navigate towards the source of alternative data and the information needed for the reconsideration. In addition, the Transformation tables and Data tables became a useful instrument for documenting all the estimation process, and the data and information used in every try. This enables the modeler, reviewers, and future users of the CFSM to clearly trace the work done in order to understand, discuss, and improve it in the future. The thorough method of documentation used in building the CFSM will allow for avoiding the lack of transparency resulting from the high complexity of some forest sector models (CFSM included, for its present state and the projected expansion in the future – Phase II), which is one of the issues of this type of models, as reported by Toppinen & Kuuluvainen (2010).

Future work on the CFSM is expected to include re-estimating some of the equations of CFSM-I, upon additional improvement and future availability of data, which might in turn require that the data series used during CFSM-I might have to be adjusted to match the reporting parameters of Colombia´s National Accounts System, and/or other data units. To guarantee a smooth process, the virtual library and Data tables will be useful in locating the original data, updating the records with the new data, and continuing the desired work. Also, when the time comes to add the non-wood forest products and the forest ecosystem services (Phase II of the CFSM), the whole database will reach its maximum utility in its main role of acting as a guide when organizing the rest of the information for forest sector modelling (e.g. additional information to what is already available on the virtual library for natural forests, other forest plantations different to the commercial ones, agroforestry systems), as well as in documenting the process of developing Phase II, in addition to retrieving information on Phase I. Given that Phase II will include adjustments on the equations of the Unprocessed Wood Market (sub)model – UWM estimated in Phase I, which will be affected by the inclusion of the non-wood-forest products and the forest ecosystem services, this further validates the necessity of the detailed cataloguing of the original data and sources.

4.3 Summary of sources of raw data, data estimations and unavailable data

4.3.1 Sources

Colombian and international databases and publications were the main sources of raw data for the period 1970-2018. Colombia´s National Account Supply and Use tables (also known as equilibriums) for the bases 1975, 1994, 2005 and 2015, prepared by DANE, were the source for the monetary values representing the quantities of supply (production), consumption, exports, and imports in the equations of the markets modelled under Phase I of the CFSM: the manufactured wood products of the wood, furniture and pulp & paper industries, and the unprocessed wood for firewood and for manufactured wood products industry and final uses other than firewood. Data for representing the variables Labor and Capital in the equations of Supply (Production) for the wood, furniture and pulp & paper industries were sourced from Colombia's Manufacturing Annual Survey, administrated by DANE. For explanatory variables in the equations of consumption, exports and imports and their corresponding price-equations, the World Bank's World Development Indicators database, the Federal Reserve Bank of St Louis Economic Data (FRED) databases, the Central Bank of Colombia (Banco de la República de Colombia, in Spanish) economic databases, DANE databases and publications and Fedesarrollo's Enterprise (Industrial) Opinion Survey were the main source of data.

Sources for raw data used for generating the time series of Total Volume of Available Stock of unprocessed wood for supply at the beginning of each year from forest plantations ($VAST_t^{MWfprw}$) included:

1. Four national detail reports of planted area - one of gross area for 1973 by Coy (1976) and three for net area for 1994 by SITEP (1996), 2015 from the Profor Project by Held et al (2017) and 2019 by MADR (2020), the last two based on ICA´s Commercial Forest Plantation Registration Database.

2. Several reports on annual gross planted area covering the different (sub)periods of the 1966-2019 period and diverse aggregation levels such as: detail data by *Departamento*[24] and species by Coy (1976) for 1966-1974; aggregated data by *Departamento* by Fondo Financiero Agropecuario -FFA (1986) covering 1975-1986; the database at the level of municipalities and species by SIEF (1998) for the period 1994-1997; aggregated national data collected by Barrera & Berrio (2007) for 1969-2006, which additionally includes lost planted areas, harvested planted areas and harvested volumes; databases of forest plantations established by using the Forest Incentive Certificate – CIF by MADR (2020) for 1994 -2012 and by FINAGRO (2020) for 2012-2020 which also included lost areas,

[24] *Departamento* (Spanish name) is the political division of Colombia, which aggregates several municipalities under its territorial jurisdiction.

GPS location, species and owner; detail reports of the ICA's Commercial Forest Plantation Registration Database for years 2013, 2017, 2019 and 2020.

3. Several reports on volumes of unprocessed wood for manufactured wood products & for final use other than firewood (MWrw) and unprocessed wood for firewood (FWrw) removed from Colombian forests such as: 1970-2019 production data reports of FAOSTAT (forestry online database); 2005-2019 Supply-Use-Balances data from DANE's Environmental Satellite Account; Barrera & Berrio (2007) 1969-2006 data on harvested volume from commercial forest plantations; MWRw transportation (*movilización* in Spanish) data from SIEF's 1994-1997, SNIF[25] 2000-2014 databases, reports of Regional Environmental Authorities and the MADS covering 2000-2018; 2018 - 2019 SUN[26] and SUNL databases, and 2007 -2019 ICA´s databases on certificate of transportation for wood from commercial forest plantations and agroforestry systems.

The summary of sources for each variable of the CFSM Phase I is presented later in table 4-1.

4.3.2 Data estimations

As some of the data necessary for the statistical estimation of some equations of the CFSM-I was not readily available, several estimations to generate this data were carried out. Data generated by estimation covered: the 1970-1993 quantities of supply (production), consumption, exports and imports for the (sub)markets of unprocessed wood for manufactured wood products & for final use other than firewood (MWrw) and unprocessed wood for firewood (FWrw); the 1970-1974 quantities of supply (production), consumption, exports and imports for the (sub)markets of manufactured wood products form the wood, furniture, and pulp & paper industries ; the 1970 – 2018 quantities for supply (production) and imports at purchaser prices; the 1970-2018 prices of Supply (production), consumption, exports, and imports; 1970-2018 value of the assets for wood, furniture and pulp & paper industries; the 1970 -2018 Colombia's wealth; the Capacity Utilization Rate (CUR) data for years 1970, 1973, 1979, 1982-2003 for all three manufactured wood industries

[25] Forest National Information System (SNIF by its acronym in Spanish).

[26] National Certificate for transportation of wild flora and its products (Salvoconducto Unico Nacional SUN) and SUN online (Salvoconducto Unico Nacional en Linea SUNL, in Spanish)

modelled, and the 2004-2013 data of CUR for the furniture industry; and 1954 – 2019 Total Volume of Available Stock of unprocessed wood for supply at the beginning of each year from forest plantations ($VAST_t^{MWfprw}$).

For the 1970 – 1993 quantities of supply (production), consumption, exports and imports for the (sub)markets of MWrw and FWrw, the estimation consisted in separating data for MWrw and FWrw from aggregated data for Forestry (Division 04 of the Colombia's National Accounts in the base 1975). The original raw data presented in the 1970 – 1993 Supply and Use tables for the base 1975, represent the sum of MWrw, FWrw and non-wood forest products[27]. Initially, intermediate consumption shares by activity branch and final consumption were estimated using the information and shares presented in the 1994-2005 Supply and Use table (base 1994), which have separated data for MWrw and FWrw. For MWrw, forestry data was assigned only to intermediate consumption by the activity branches of Mining, Wood and Furniture, Paper and Print, Construction and Public works, Transportation and Storage, Communications, and Government Services. In turn, FWrw was assigned to intermediate consumption on agricultural activities (which exclude forestry) and to final consumption. Then, exports and imports of MWrw and FWrw were assigned using 1970-1995 trade data for the Colombian forest sector collected in 1996 by the Colombian Forest Statistics Information System (SIEF), which contains detailed data on exports and imports of both MWrw and FWrw. Finally, the supply (production) of MWrw and FWrw was calculated by using the difference of the equilibrium quantities estimated minus imports. More details on this estimation, for example the treatment of import taxes, stock variation, other taxes on production and gross capital formation, are found in the following path of the electronic file of the virtual library of CFS-DB:

Appendices\Appendix4_1_sector_specific_database\4_Virtual_Library\Files_related_Eq_1-16_IDM\DANE_CN\CNB1975\EstimacionTroncosdeMaderayLeña1970-1994.

A similar approach to the one presented above was used to estimate the 1970-1974 quantities of supply (production), consumption, exports, and imports for the (sub)markets of manufactured

[27] The unpublished 1970 – 1993 Supply and Use tables for the base 1975 (handed out by DANE to the researcher in 2019) are part of a reconstruction of these tables for an exercise conducted recently by DANE to express 1975-2017 GDP time-series on just one base: 2005. Although reconstructed in detail for the components of forest sector in the National Accounts of Colombia (i.e., Forestry, Wood, Furniture and Pulp and Paper Industry), these tables have only aggregated data for the category of Forestry, which is the summation of MWrw, FWrw, and non-wood forest products.

wood products of the wood, furniture, and pulp & paper industries. For this period, the supply and use tables contain only aggregated data for both wood industry and furniture industry, and for both the pulp & paper industry and print industry, respectively. Details on this estimation can be found in the following path of the electronic file of the virtual library of CFS-DB:

Appendices\Appendix4_1_sector_specific_database\4_Virtual_Library\Equations\Eq10_Stw\Data_1970_2018\Eq_10_Assets.xlsx sheets NoteB.corrientes (3) and NoteC.constantes (2).

Estimation for the 1970 – 2018 quantities for supply (production) and imports at purchaser prices[28], involved converting these two aggregates from basic prices (as found in the Supply and Use tables) to purchaser prices. The first step was the separation of margins (commercialization and transportation) for the national production and imports, which are aggregates in the Supply and Use tables. To get the separate margins for supply and imports, the total value of the margins was multiplied by the weight of each aggregate within their sum. Once the margins were separated, the values of the quantities of supply and imports at purchaser prices were calculated as the sum of values at basic prices, plus taxes and margins for each variable. Details on this estimation can be found in the following path of the electronic file of the virtual library of CFS-DB:

Appendices\Appendix4_1_sector_specific_database\4_Virtual_Library\Equations\Eq10_Stw\Data_1970_2018\Eq_10_Assets.xlsx sheets NoteB.corrientes (3), NoteD.corrientes94, NoteF.Corrientes05, NoteJ.OCorrientes2015.

As data for prices of the forest products in different local markets is rather scarce in Colombia, 1970-2018 prices of supply (production), consumption, exports, and imports were estimated using their deflators, as per Kant et al. (1996). These deflators were estimated, correspondingly, by dividing the current monetary values of the quantities of supply (production), consumption, exports, and imports by their constant monetary values.

The estimation for 1970-2019 values of the assets for machinery & equipment and building & structures for wood, furniture and pulp & paper industries comprised an adjustment to the 1994-2018 original time series to make the series comparable, and the estimation of these data for the period 1970-1993, which were unavailable in DANE’s reports on the Annual Manufacturing Survey (EAM by its acronym in Spanish). Value of assets, at the end of each year, has been

[28] Equations of the Phase I of the CFSM are estimated on the bases of values at purchaser prices.

reported in the EAM since 1992 on, but it took 1992 and 1993 to refine the methodology and adjust the details of the information captured by the EAM (DANE, 2020). Since 1994, the instrument to capture the value of assets in the EAM has been more consistent, hence, data for year 1994 was used as the starting point for adjustment and estimation.

For 1994, the value of assets for machinery & equipment and building & structures at the end of the year was estimated as the value reported by DANE in the EAM for 1994 less the sum of the annual revalorization of these assets since they were introduced in the EAM in 1978, up to, and including 1994[29]. Once the value for 1994 was determined, the value for 1995 was generated by adding the value of the Gross Investment in 1995 (as reported by the EAM) to the 1994 value of assets. The gross investment reported in the EAM is defined as the sum of investment in new, used, and produced by its own used less the sales of them during a given year (DANE, 2000). Data for the years 1996 to 2018 was generated by the same method as per 1995, using the value of fixed asset estimated in the preceding year. The value for 1993 was generated by subtracting the value of the Gross Investment in 1993 (as reported by the EAM) to the 1994 value of assets. Data for 1970-1992 were produced by the same method as per 1993, using the value of fixed asset estimated in the succeeding year. Details on this estimation can be found in the following path of the electronic file of the virtual library of CFS-DB:

Appendices\Appendix4_1_sector_specific_database\4_Virtual_Library\Equations\Eq10_Stw\Data_1970_2018\Eq_10_Assets.xlsx sheet InveactivosEAM-MSFCJune17-2

As time series data on Colombia's wealth are unavailable for most of the period 1970-2018 (OECD 2020; Lopez & Salamanca 2009), the corresponding time series was estimated following the

[29] Since 1992, in the EAM, the concept of revalorization was changed to revalorization net of de-valorization. According to DANE (2020): a) in 1978, an important number of establishments that had been doing annual revalorizations of fix assets, asked DANE to include this information into the EAM. DANE accepted, and since that year included the revalorization of fixed assets only if it represented an increase in the value of assets in the accounting books at the end of the year. DANE suggests that, for making the data on assets comparable with former years, this value should be subtracted. b) Between 1992 and 1994 this value was replaced by valorization (net of de-valorization) of fixed assets caused during the year (as accounting practices allowed for it), however DANE only accepted this information if it was not an effective increase or decrease of assets in the accounting books at the end of the year. c) Since 1993 up to 2006 DANE asked for the value of assets adjusted by inflation and separately the value of this adjustment. Since 2007 this adjustment is not present in the EAM. DANE reports that the adjustment for inflation is the reason why the value of fixed assets presents important variations when compared with its corresponding indicator in former EAM. Hence, a reasonable approach to make the data from 1970 to 2018 comparable, is to eliminate from the data the components of valorization, revalorization, and inflation adjustment, as they do not represent new investments or de-investments but changes in the way the actual assets are valued financially.

definition used in the FOCUS model of the Canadian Economy, reported by Kant et al. (1996). In the FOCUS model, wealth is defined as Capital Stock plus public debt (eroded by inflation) minus external debt. The time series for Capital Stock, in 2011 USD, was sourced from the FRED database, which collected this information for the University of Groningen and University of California, Davis, and from The Next Generation of the Penn World Table (2015) by Feenstra et al. The source for time series of Public and Private external and internal debt was the Central Bank of Colombia. Details on this estimation can be found in the following path of the electronic file of the virtual library of CFS-DB:

Appendices\Appendix4_1_sector_specific_database\4_Virtual_Library\Equations\Eq10_Stw\Data_1970_2018\Eq_13_Assets.xlsx sheet NW

Approaches for estimating unavailable data for Capacity Utilization Rate (CUR), based on the correlations between CUR data available for the forest industries and several 1970-2018 times series available in the EAM, were investigated. Examples of the correlations studied included CUR and annual energy consumption by each industry, CUR and gross production, and CUR and raw materials bought. Correlation between CUR for each of the forest industries and CUR for Colombia's manufacturing industry were also tested. As none of the correlations studied was satisfactory for estimating the data for all the years needed, it was decided to input the annual average CUR data for Colombia's manufacturing industry for years 1970, 1973, 1979, 1982-2003 for all three manufactured wood industries modelled, and the 2004-2013 CUR data for the furniture industry. Details can be found in the following path of the electronic file of the virtual library of CFS-DB:

Appendix4_1_sector_specific_database\4_Virtual_Library\Files_related_Eq_1-16_IDM\ZDANE&OTROS\CUR_Estimation

Finally, the estimation for the 1954 – 2019 ($VAST_t^{MWfprw}$) started with the generation of the following consolidated annual times series unavailable for Colombia: a) gross planted area, b) gross cumulated planted area, c) lost planted area, d) harvested planted area, d) net planted area, and e) cumulated net planted. It was followed by estimating the 1953 – 2019 Total Volume of Available Stock of unprocessed wood for supply at the end of each year from forest plantations (VAS_t^{MWfprw}), using the SCRPFC. Before generating the annual VAST, it was also necessary to estimate the annual volume harvested VH, legal and illegal, from all national sources of wood, and then separate this VH^{MWrw} into the share for forest plantations (VH^{MWfprw}) and natural forests (VH^{MWnfrw}), by using the sources of data listed in section 4.3.1. Finally, $VAST_{1955}^{MWfprw}$ was estimated as VAS_{1954}^{MWfprw} as there was no VH^{MWfprw} for year 1954 or before. $VAST^{MWfprw}$ for each year of the 1956-2019 series was then generated by using the identity 3-44 ($VAST_t^{MWfprw} = VG_{t-1}^{MWfprw} - VH_{t-1}^{MWfprw}$), and identity 3-45 ($VG_{t-1}^{MWfprw} = VAS_{t-1}^{MWfprw} – VAS_{t-2}^{MWfprw}$).

The estimations of VH, VAS and VAST were quite detailed. Information on the process of estimation and results for VH was organized in the electronic files found in the virtual library of CFS-DB, in the following path:

Appendix4_1_sector_specific_database\4_Virtual_Library\4_Virtual_Library\VHEstimation\VH Estimation.xls.

Information for VAS and VAST was arranged in the Colombian Forest Plantation database (CFPD-DB), which comprises 30,998 records of all forest stands ever planted up to December 31st, 2019 (e.g. history of planting, lost, harvesting, and replanting areas). Detailed documentation about estimation of VAS and VAST and the CFPD-DB and its documentation can be found in the following path of the electronic files of the virtual library of CFS-DB:

Appendix4_1_sector_specific_database\4_Virtual_Library\4_Virtual_Library\ Colombian_Forest_Plantations_Database\CFPD-DB.xls.

The summary of data estimations for variables used in CFSM Phase I is presented later in table 4-1.

4.3.3 Unavailable data

The extra efforts made in this research to obtain all data required for estimating the theoretical equations of the CFSM Phase I presented in chapter 3 were not always successful. In addition to the data not available discussed in section 3.2, some data was also not available for most (or all) of the years of the time-period considered for the equation estimation and validation (i.e., 1975-2018). In some cases, data for a proxy variable was available, hence the corresponding variable (or units) considered initially in the theoretical equation was replaced by this new variable (or units) as follows.

The units for the variable housing construction (HCS) was changed from number of dwellings started and finished in each year to square meters approved for construction, the World's Industrial Production Index (IPI) was replaced by United States of America's IPI, and the World Exports Price Index (WEPI) for each forest industry modelled was substituted with the US Producer Price Index by Commodity, generated by each forest industry modelled (i.e., wood, furniture and pulp and paper). In addition, the variable Labor in equations 3-42 and 3-43 were replaced by the rural population.

The following variables were dropped from the theoretical equations as neither direct data nor a proxy was available: labor and capital for the logging industry of commercial forest plantations (L_t^{MWfprw} and K_t^{MWfprw}) and the variable GEN_t^{MWfprw} which captures other costs of harvesting not captured by the L_t^{MWfprw} and K_t^{MWfprw} variables in equation 3-41; $VAST_t^{MWnfrw}$, K_t^{MWnfrw} and GEN_t^{MWnfrw} in equation 3-42; $VAST_t^{FWnfrw}$ and the variable GEN_t^{FWnfrw} which is a control variable for all costs of harvesting wood for firewood in equation 3-43; and the variable geographic location (GEO) in equation 3-49. Also, during the period 1970-2018 Colombia did not export or import firewood. Hence, no data was available for estimating imports and exports equations and the respective prices equations.

The variables (original or proxy), for which data was finally available for parameter estimations in any of the theoretical equations of the CFSM Phase I is presented in Table 4-1. The raw data for these variables is presented in the Raw data table (*sheet E#-Rawdata*) of the electronic file of each equation in the virtual library, following the path:

Appendices\Appendix4_1_sector_specific_database\4_Virtual_Library\Equations Eq#_#\Data_1970_2018\Eq_#_#.xlsx [30].

4.4 Data transformations for the CFSM Phase I (CFSM-I) final estimated equations

Once the time series which best represented the variables for each of the theoretical equations was selected from the raw data tables, some transformations were necessary to complete the data

[30] # represents the number of the equation and/or some additional text in the name of the folder, file or a sheet of an Excel file.

consolidation process. Those transformations included: standardizing units, base-year and scale changes, and variable normalization, the latter to achieve stationarity in time series.

Monetary values of all variables were finally converted to thousand million Colombian Pesos (COP), changed to the base year 2015 and converted to 2015 constant prices when necessary. Linking the time series for bases 1975, 1994, 2005 and 2015, in current values, followed the method of geometric interpolation in reverse (named by DANE: “retropolación” in Spanish). This method maintains unaltered the values of the base years, which are maintained as references in order to distribute, proportionally, the difference between the nominal value for the new year base and the nominal value for the former year base, with the difference calculated for the year in which the new base is implemented (DANE 2013, DANE 2020). For linking the time series of the mentioned bases, in constant values, the variation rate method was used. This method maintains unaltered the temporal characteristics of the original values (DANE 2013). Both methods are explained in detail in DANE (2013). Graphical analyses were performed to check the consistency of the results of applying this method for the aggregate variables of production, consumption, exports, and imports of the Colombian forest sector.

On the other hand, all indexes and deflators were rescaled to the base year 2015 (i.e., 2015 = 1). Finally, for the equations explaining Consumption (C), this variable and the variable wealth (W) were normalized by dividing by Colombias’ Total income (Income per household times number of households), and the variables of Housing Construction (HCS), Population (N) and Rural Population (NR) were normalized dividing by Colombia’s Number of Households (NHH)[31].

These transformations are presented in detail in the Transformation tables of each variable in the electronic files of every equation of the CFSM Phase I. Transformation tables for every variable can be found in the electronic file of each equation in the virtual library, following the path:

[31] Data for average square meters of dwellings by households during the period 1970 to 2018 in Colombia are scarce and covered only some recent years. Although several tries were made for having this data estimated, the intents were unsuccessful. Hence the variable HCS were normalized, preliminary, only by the number of households. As HCS is measured in square meters approved for construction, the normalization should have been done diving HCS by the number of households times the average of square meters by dwelling to cancel out the units in the numerator and denominator in equations 3-13 and 3-14.

Appendices\Appendix4_1_sector_specific_database\4_Virtual_Library\Equations Eq#_#\Data_1970_2018\Eq_#_#.xlsx

Original and normalized variables, and their corresponding units of the consolidated time series are summarized in table 4-1. Consolidated data (i.e., time series) used as inputs for the process of equation estimation are presented in the consolidated data table (sheet Consolidateddataalloptions) of the electronic file of each equation. This tables can be accessed following the path:

Appendices\Appendix4_1_sector_specific_database\4_Virtual_Library\Equations Eq#_#\Eq_#_#.xlsx

4.5 Consolidated sectoral products

Colombia has serious issues with producing, collecting, consolidating, and disseminating forest sector data and information in general. The Guidelines for the policy of commercial forest plantation for wood production and its value chain (Martínez-Cortés et al. 2017a) state that "Production, quality, and availability of forest information in Colombia is not adequate, reliable, timely, and of easy access… and in particular, they lack in uniformity and information consolidation for the commercial forest plantations and its value chain, and the process for capturing, processing, disseminating, and tracing it is pretty weak."

During the data consolidation process, several statistical indicators characterizing the forest sector in Colombia were obtained for the first time. These indicators have been converted into consolidated sectoral products by graphical, analytical and economic analysis. To save space, these consolidated sectoral products have been moved to Appendix 4-2 and 4-3.

Appendix 4-2 presents the consolidated products related to volumes of wood needed to estimate the VAST of Colombia's commercial forest plantations, a key policy variable of the CFSM-I. It includes the evolution of Colombia´s area of commercial forest plantation for wood production (CFPm) since its inception in the 1950s to date, the 1950-2019 total volume of available stock of unprocessed wood for supply the manufactured wood products industry from CFPm at the end of each year (VAS), and the 1970-2019 volumes harvested (VH) from Colombia´s CFPm and natural forest (including wood illegally logged).

Appendix 4-3 is devoted to explaining the evolution of the Colombian wood forest products markets. Consolidated data obtained in this chapter about supply, demand and its components (consumption, exports and imports), and prices sourced and derived from the Supply and Use Tables of the National Accounts of Colombia, is used jointly with complementary material from other sources to present the main characteristics of the five markets modelled under CFSM I: manufactured wood products of the wood, pulp & paper and furniture industries, the unprocessed wood for firewood, and the unprocessed wood for the manufactured wood products industry and rural uses other than firewood. The characteristics of their aggregate market, i.e., the Colombian wood forest product market, and each of the five single markets that make up it, and their analysis is divided into three segments: Demand & Supply, Trade balance, and Market clearing evidence. To better understand the analysis of each market, the appendix first presents some context on how the forest sector has been considered into the National Accounts, and some useful caveats for the treatment of the statistics of gross capital formation and terminology.

Aside from it being novel information for the Colombian forest sector, the consolidated sectoral products offered in these Appendices 4-2 and 4-3 exemplify (for beginner modelers) how to gain more insight on the target to be modelled, the suitability of the theoretical framework selected for modelling and the richness of National Accounts for analytical modelling of forest sectors in the tropical world. They also are important contributions of this research, aiming to improve the situation of the forest sector information described above.

Table 4-1 Variables (original and proxy) of the CFSM Phase I (CFSM-I), for which consolidated time series were available or estimated, units and sources.

Variable abbreviation	Name of original (or proxy) variable	Variable superscript (group of products or market)	Consolidated time series that could represent the variable (1970-2018)	Units of the consolidated data	Sources of Data*
C	Consumption	MWrw	Intermediate consumption at purchaser's prices	2015 Thousand million COP	1
C	Consumption	w, z, FWrw	Intermediate+Final consumption at purchaser's prices	2015 Thousand million COP	1
C	Consumption	f	Intermediate+Final consumption+Gross Fixed Capital Formation (GFKF) at purchaser's prices	2015 Thousand million COP	1
C / Y	Normalized consumption	MWrw	Intermediate consumption at purchaser's prices / Gross disposable income	2015 Thousand million COP / 2015 Thousand million COP	2
C / Y	Normalized consumption	w, z, FWrw	Intermediate+Final consumption at purchaser's prices / Gross Disposable Income	2016 Thousand million COP / 2015 Thousand million COP	2
C / Y	Normalized consumption	f	Intermediate+Final consumption+Gross Fixed Capital Formation (GFKF) at purchaser's prices / Gross Disposable Income	2017 Thousand million COP / 2015 Thousand million COP	2
C / YP	Normalized consumption	MWrw	Intermediate consumption at purchaser's prices / Permanent income	2018 Thousand million COP / 2015 Thousand million COP	2
C / YP	Normalized consumption	w, z, FWrw	Intermediate+Final consumption at purchaser's prices / Permanent income	2019 Thousand million COP / 2015 Thousand million COP	2
C / YP	Normalized consumption	f	Intermediate+Final consumption+Gross Fixed Capital Formation (GFKF) at purchaser's prices / Permanent income	2020 Thousand million COP / 2015 Thousand million COP	2
CT	Total consumption	rw	Intermediate+Final consumption at purchaser's prices	2015 Thousand million COP	1
CT	Total consumption	MW, WFP	Intermediate+Final consumption+Gross Fixed Capital Formation (GFKF) at purchaser's prices	2015 Thousand million COP	1
CUR	Capacity utilization rate	w, z, f, MW	Capacity utilization rate	Percentage	3
D	Demand	w, z, f, MWrw, FWrw	Demand at purchaser's prices	2015 thousand of million COP	1
DT	Total demand	MW, rw, WFP	Total demand at purchaser's prices	2015 thousand of million COP	1
HCS	Housing construction starts (Approved area for housing construction as proxy for HCS)		Approved area for housing construction	Thousand of square meters approved for construction	4
HCS / NHH	Nomalized housing construction starts		Approved area for housing construction / Households	Thousand of square meters approved for construction / Thousand households	2
i	Inflation		Consumer price index	Percentage	5
IPI	Global Industrial Production Index (US IPI as proxy for Global IPI)		US Industrial Production Index, Annual, Seasonally Adjusted	Unitless, 2015 = 1	6
K	Capital	w, f, z	Value of fixed assets in accounting books, at 31st of December	2015 Thousand million COP	8
K	Capital	w, f, z	Gross investment in Buildings and Structures	2015 Thousand million COP	8

Variable abbreviation	Name of original (or proxy) variable	Variable superscript (group of products or market)	Consolidated time series that could represent the variable (1970-2018)	Units of the consolidated data	Sources of Data*
K	Capital	w, f, z	Gross investment in Machinery and Equipment	2015 Thousand million COP	8
K	Capital	w, f, z	Gross investment in Machinery and Equipment + Buildings and Structures	2015 Thousand million COP	8
K	Capital	w, f, z	Value of Building and Structures, at 31st of December	2015 Thousand million COP	8
K	Capital	w, f, z	Value of Machinery and Equipment, at 31st of December	2015 Thousand million COP	8
K	Capital	w, f, z	Value of Machinery and Equipment + Building and Structures, at 31st of December	2015 Thousand million COP	8
L	Labor	w, f, z	Employment	Number	8
L	Labor (NR as proxy for Labor)	MWrw, FWrw	Rural population as proxy for Employment	Number	5
M	Imports	w, z, f, MWrw, FWrw	Imports at purchaser's prices	2015 Thousand million COP	1
MT	Total imports	MW, rw, WFP	Total imports at purchaser's prices	2015 Thousand million COP	1
N	Total Population		Total population (midyear estimates)	Thousand people	5
N / NHH	Normalized population		Total population / Households	Thousand people / Thousand households	2
NHH	Households		Households	Thousand	9
NR	Rural population		Rural population	Thousand	5
NR / N	Normalized rural population		Rural population / Total pupulation	Thousand people / Thousand people	2
NR / NHH	Normalized rural population		Rural population / Households	Thousand people / Thousand of households	2
PC (with superscript)	Consumption price	w, z, FWrw	Consumption price deflator (Weighted average for Intermediate and Final consumption) = Consumption in current values / Cosumption in constant values	Unitless, 2015 = 1	10
PC (with superscript)	Consumption price	f	Consumption price deflator (Weighted average for Intermediate, Final consumption and Gross Fixed Capital Formation) = Consumption in current values / Cosumption in constant values	Unitless, 2015 = 1	10
PC (with superscript)	Consumption price	MWrw	Consumption price deflator = Consumption in current values / Cosumption in constant values	Unitless, 2015 = 1	1

Variable abbreviation	Name of original (or proxy) variable	Variable superscript (group of products or market)	Consolidated time series that could represent the variable (1970-2018)	Units of the consolidated data	Sources of Data*
PC / Ph	Relative price of consumption	MWrw	Consumption price / Price of housing	Unitless, 2015 = 1 / Unitless, 2015 = 1	2
PC / Phcm	Relative price of consumption	w, f, MWrw	Consumption price / Price of housing construction materials	Unitless, 2015 = 1 / Unitless, 2015 = 1	2
PC / PM	Relative price of consumption	w, f, z, MWrw	Consumption price / Import price	Unitless, 2015 = 1 / Unitless, 2015 = 1	2
Ph	Price of housing		Used housing price index	Unitless, 2015 = 1	12
Phcm	Price of housing construction materials		Producer price index by economic destination or use: Construction materials	Unitless, 2015 = 1	12
PM	Import price	w, f, z, MWrw, FWrw	Import price deflactor = Import in current values / Import in constant values	Unitless, 2015 = 1	10
PS	Supply price	w, f, z, MWrw, FWrw	Supply price deflactor = Supply in current values / Supply in constant values	Unitless, 2015 = 1	10
PS / PS	Relative price of supply	MWrw, FWrw	Supply price / Supply price	Unitless, 2015 = 1 / Unitless, 2015 = 1	2
PX	Export price	w, f, z, MWrw	Export price deflactor = Export in current values / Export in constant values	Unitless, 2015 = 1	10
RX	Exchange rate		Official exchange rate (UMN per US$, average for a period) or Exchange rate, national currency (COP)/USD (market+estimated)	COP/USD	6
RX	Exchange rate		Exchange rate index - Calculated based on exchange rate of Federal Reserve Bank of St. Louis	Unitless, 2015 = 1	6
S	Supply	w, f, z, MWrw, FWrw	Total gross production at purchaser's prices	2015 Thousand million COP	1
S	Supply	MWrw (MWfprw+MWnfrw)	Total gross production at purchaser's prices, weighted by the volume of unprocessed wood by source	2015 Thousand million COP	1
S	Supply	MWrw, FWrw	Production quantity	Million cubic meters of under bark roundwood	13
S / Y	Normalized supply	w, f, z	Total gross production at purchaser's prices / Income	2015 Thousand million COP / 2015 Thousand million COP	2
ST	Total supply	MW, rw, WFP	Total gross production at purchaser's prices	2015 Thousand million COP	1
U	Unemployment		Overall unemployment rate (average of each year)	Percentage	14
VAS	Total Volume of available stock of unprocessed wood for Supply at the end of a year as provides by the SCRPFC	MWrw (MWfprw+MWnfrw), FWrw	Volume of available stock of unprocessed wood for Supply at the end of a year	Million cubic meters of under bark roundwood	15
VAST	Total Volume of available stock of unprocessed wood for Supply at the beginning of a year	MWrw (MWfprw+MWnfrw), FWrw	Volume of available Stock [(unprocessed) wood] for Supply at the beginning of a year after discounting VH from the last year	Million cubic meters of under bark roundwood	16

Variable abbreviation	Name of original (or proxy) variable	Variable superscript (group of products or market)	Consolidated time series that could represent the variable (1970-2018)	Units of the consolidated data	Sources of Data*
VG	Net growth (in volume) in a year (Growth – Mortality)	MWrw (MWfprw)	Net growth (in volume) in a year (Growth – Mortality)	Million cubic meters of under bark roundwood	17
VH	Volume harvested during each year	MWrw (MWfprw+MWnfrw)	Volume harvested during each year	Million cubic meters of under bark roundwood	13
W	Wealth		Estimated wealth = Capital stock + Public debt - External debt	2015 Thousand million COP	18
W / Y	Normalized wealth		Wealth / Income	2015 Thousand million COP / 2015 Thousand million COP	2
W / YP	Normalized wealth		Wealth / Permanent income	2015 Thousand million COP / 2015 Thousand million COP	2
WEPI	World Exports price Index (US Producer Price Index by Commodity as proxy for Global WEPI)	w	US producer price index by commodity for lumber and wood products	Unitless, 2015 = 1	6
WEPI	World Exports price Index (US Producer Price Index by Commodity as proxy for Global WEPI)	f	US Producer Price Index by Commodity for Furniture and Household Durables: Household Furniture	Unitless, 2015 = 1	6
WEPI	World Exports price Index (US Producer Price Index by Commodity as proxy for Global WEPI)	z	US Producer Price Index by Commodity for Pulp, Paper, and Allied Products	Unitless, 2015 = 1	6
X	Exports	w, z, f, MWrw, FWrw	Exports at purchaser's prices	2015 Thousand million COP	1
XT	Total exports	MW, rw, WFP	Total exports at purchaser's prices	2015 Thousand million COP	1
Y	Total income		Gross Disposable Income	2015 Thousand million COP	5
Y / NHH	Normalized Income		Income / Households	2015 Thousand million COP / Thousand households	2
YP	Permanent income		Permanent income	2015 Thousand million COP	2
YP / NHH	Normalized Transitory Income		Permanent income / Thousand households	2015 Thousand million COP / Thousand households	2
YTr	Transitory Income		Transitory Income	2015 Thousand million COP	2
YTr / NHH	Normalized Transitory Income		Transitory income / Thousand households	2015 Thousand million COP / Thousand households	2

Sources: 1) DANE, Colombia's National Accounts Supply and Use Tables, base 1975, 1994, 2005 and 2015; (2) Calculated in this research; (3) Thoumi (1971) Study for National Department of Planning, Coyuntura Economica Journal (1972-1990) based on Fedesarrollo's Industrial Survey and Enterprise Opinion Survey (industrial Sector), and Fedesarrollo's Capacity utilization rate database (1991-2019) based on Fedesarrollo's Entrerprise Opinion Survey; (4) DANE, Construction licenses, 1970 - 2019; (5) World Bank, World Development Indicators; (6) Federal Reserve Bank of St. Louis; (7) DANE, Producer price index statistics; (8) DANE, Manufacturing Annual Survey; (9) DANE, Colombia's Household Survey (1970 - 1978), and Colombia's Households 1985-2005 Estimations and 2006-2020 Projections, 1979 - 1984 Estimations based on population by the author of this research; (10) Calculated based on DANE, Colombia's National Accounts Supply and Use Tables, base 1975, 1994, 2005 and 2015; (11) Colombia's Central Bank - Consumer's price index. Estimated base on CPI 2018-base (Dec 2018=100); (12) Central Bank of Colombia; Used Housing Price Index (IPVU)_Base 1990 = 100. 1.1.1. Nominal and real index - Total, by city, VIS and non VIS_annual periodicity and real estate prices in the housing market in Bogota 1970-2004 Samuel Jaramillo González (2004). CEDE Document 2004-42 ISSN 1657-7191 (Electronic Edition) October, 2004. https://www.academia.edu/7380909/Precios_inmobiliarios_de_vivienda_en_Bogot%C3%A1_1970-2013; (13) Estimated based on Several National Sources of Data and FAO; (14) DANE, DANE's Statistical Yearbook (1970-1975), DANE's historical time series 1976 -1983, 1984-2000, DANE Household Survey 2001-2017 and DANE's Website 2018; (15) Estimations based on VAS and multiple sources for forest plantations area and volume; (16) Estimated using SCRPFC and several national sources of forest plantations data; (17) Estimated using SCRPFC; (18) Federal Reserve Bank of St. Louis (for Capital Stock), Central Bank of Colombia (Public Debt and External Debt).

Chapter 5
Calibration - Estimation, Validation, and Software Application for the CFSM-I

5.1 Introduction

In addition to the data consolidation process presented in chapter 4, calibration of the CFSM Phase I (CFSM-I) includes the estimation of parameters of the theoretical behavioral equations specified in the structure of the model, presented in chapter 3. Validation of CFSM-I comprises the comparison between the model predictions and the actual data, and the evaluation of the model for its usage in various purposes (e.g. forecasting and scenario analysis). The validation process is the last stage for completing the construction of the CFSM-I.

There exist statistical techniques and specialized software that facilitate the task of parameter estimation, and, to some degree, that of the validation of any model, but none of them are perfectly suitable for the task of using the model for forecasting or performing scenario analysis. Hence, a software application for running the CFSM-I is instrumental for such uses. In this research, the software application for executing the CFSM-I also includes features for performing the validation process of the model.

The sections of this chapter are devoted to the last part of the calibration process of the CFSM-I (i.e., estimation), and the validation process. They also present and discuss elasticities for key variables of the forest sector, which can always be obtained from estimating econometric models of the forest sector. To conclude the chapter, some general characteristics of the software application for running the CFSM-I are presented. Appendices detail the information presented in this chapter.

5.2 Parameter estimation of behavioral equations of the CFSM-I

In selecting the method for estimating the behavioral equations of the CFSM-I, the first two model assumptions for building the CFSM were key. Following the first assumption that each of the five single markets modelled (FWrw, MWrw, w, f, and z[32]), and the aggregate markets (rw or UW, MW, and WFP) are represented by a simultaneous-equation model (a structural model), both limited information and full information methods were considered in the outset for estimating the parameters of such models[33]. Consequently, with the second assumption that behavioral equations in each simultaneous-equation model represent key sectoral endogenous variables of the model (Supply, C, X, M and prices of C, X and M), which relates to a series of predetermined variables by linear relationships, the estimation techniques of full information maximum likelihood (FIML), Ordinary least squares (OLS), Indirect least squares (ILS) and Two-stage least squares (2SLS) were then contemplated[34]. After careful consideration of the methods and techniques, the OLS technique (a limited information method) was selected as the most appropriate for carrying out the parameter estimation of the final 32 multiple regression equations included in the CFSM-I, 21 for the MWM (sub)model, and 11 equations for UWM (sub)model[35].

Consolidated data presented in chapter 4 was the starting point of the process of parameter estimation[36]. For the most part, consolidated data covered the period 1970-2018 (49 years), but

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[32] The Colombian forest sector comprises three aggregate markets: WFP market, Non-wood Forest Product market and Forest (ecosystem) Services market. The WFP market is the result of summing two aggregate (sub)markets: the rw market and the MW market. In turn, the rw market is the aggregate market resulting from the summation of single markets FWrw and MWrw, while the MW market is the result of adding the markets for w, f, and z. CFSM Phase I (CFSM-I) only models the WFP market and its aggregate (sub)markets, as well as single markets under (sub)models UWM and MWM. For additional details, see Chapter 3 and 5.

[33] A simple and heuristic description of the limited information methods (aka single-equation methods) and full information methods (aka system methods) are found in Gujarati and Dawn (2009).

[34] OLS, ILS and 2SLS are widely known techniques. For a heuristic explanation and examples of these techniques refer to Gujarati and Dawn (2009).

[35] Theoretical (Behavioral) Equations for (sub)models MWM and UWM of the CFSM-I to be estimated were presented in Chapter 3, Table 3-2 and 3-4, respectively. Variables of these theoretical equations for which no data was available, and no proxy variable was identified were presented in Chapter 4, under section 4.3.3. Final variables (original and proxy) considered in the theoretical equation to be estimated were presented in Table 4-1.

[36] For accessing consolidated data for each equation of the CFSM-I, go to the Digital Appendix of this thesis document and follow the path *Appendices\Appendix4_1_sector_specific_database\4_Virtual_Library\Equations Eq#_#\Eq_#_#.xlsx*

the time series used for estimating the equation parameters only covered 1975-2015 (41 years). Data for the period 2016-2018 was kept for the out-of-sample validation process. Data for 1970-1974 was discarded from estimation as it was considered less reliable because additional assumptions for consolidating data for those years were needed.

The process of parameter estimation and selection of the final estimated equations followed, with some minor changes, the procedure used by Kant et al (1996, p. 1123):

a) Testing the set of predetermined variables as defined by each final theoretical behavioral equation specified in the UMW and MWM (sub)models of the CFSM-I (Tables 5-1 and 5-2), whose superscripts and subscripts, description, sources, and time series available to represent the variables and units, are summarized in Tables 5-3 and 5-4. During this routine, all time series available to represent a variable were tried, and separate estimated equations were obtained (e.g., for the variable capital in equations 10, 11 and 12 seven time series were tried). In some cases, theoretical equations of Tables 5-1 and 5-2 required an alternative specification to achieve an estimated equation complying with the statistical and economic requirements for the model. Alternative specification was done by transforming and/or adding/dropping variables. The reason for this work with the variables and the alternative specifications are discussed in this section 5.3.

b) Reviewing the assumptions of the classical normal lineal regression model, underlying the OLS estimate. This was necessary for making statistical inferences about the estimated parameters such as their precision and validity. Special attention was given to detecting and, when possible, correcting issues (if any) related to the non-normality, heteroscedasticity, multicollinearity, and serial correlation of the disturbance term.

c) Checking whether or not an estimated equation obtained by OLS was subject to first-order autocorrelation. To do so, the Durbin Watson d (DW d) statistic were used; for equations having lagged variables, Durbin h (Dh) statistic was applied, instead DW d. In cases where the estimated DW d fell in the inconclusive zone of evidence of autocorrelation, Graph methods (partial auto-correlogram) and the Run test were used. If subject to first-order autocorrelation, new equations were obtained by Prais-Winsten and Cochrane-Orcutt methods, in order to correct for first-order autocorrelation of the residuals.

Table 5-1 Theoretical Behavioral Equations of the MMW (sub)model of the CFSM-I, containing only variables (original or proxy) with available time series

Equation number	Equation name	Theoretical Behavioral Equation
5-10	Supply (Production) of manufactured wood products of the wood industry	$S_t^{w} = \beta_1^{sw} + \beta_2^{sw} PS_t^{w} + \beta_3^{sw} L_t^{w} + \beta_4^{sw} K_t^{w} + \beta_5^{sw} PC_t^{MWrw} + \varepsilon_t^{sw}$
5-11	Supply (Production) of manufactured wood products of the furniture industry	$S_t^{f} = \beta_1^{sf} + \beta_2^{sf} PS_t^{f} + \beta_3^{sf} L_t^{f} + \beta_4^{sf} K_t^{f} + \beta_5^{sf} PC_t^{MWrw} + \varepsilon_t^{sf}$
5-12	Supply (Production) of manufactured wood products of the pulp and paper industry	$S_t^{z} = \beta_1^{sz} + \beta_2^{sz} PS_t^{z} + \beta_3^{sz} L_t^{z} + \beta_4^{sz} K_t^{z} + \beta_5^{sz} PC_t^{MWrw} + \varepsilon_t^{sz}$
5-13	Consumption of manufactured wood products of the wood industry	$C_t^{w} = \beta_1^{cw} + \beta_2^{cw} PC_t^{w} + \beta_3^{cw} U_t + \beta_4^{cw} i_t + \beta_5^{cw} W_t + \beta_6^{cw} HCS_t + \beta_7^{cf} Y_t + \varepsilon_t^{cw}$
5-14	Consumption of manufactured wood products of the furniture industry	$C_t^{f} = \beta_1^{cf} + \beta_2^{cf} PC_t^{f} + \beta_3^{cf} U_t + \beta_4^{cf} i_t + \beta_5^{cf} W_t + \beta_6^{cf} HCS_t + \beta_7^{cf} Y_t + \varepsilon_t^{cf}$
5-15	Consumption of manufactured wood products of the pulp and paper industry	$C_t^{z} = \beta_1^{cz} + \beta_2^{cz} PC_t^{z} + \beta_3^{cz} U_t + \beta_4^{cz} i_t + \beta_5^{cz} W_t + \beta_6^{cz} N_t + \beta_7^{cf} Y_t + \varepsilon_t^{cz}$
5-16	Exports of manufactured wood products of the wood industry	$X_t^{w} = \beta_1^{xw} + \beta_2^{xw} IPI_t + \beta_3^{xw} PX_t^{w}/RX_t + \varepsilon_t^{xw}$
5-17	Exports of manufactured wood products of the furniture industry	$X_t^{f} = \beta_1^{xf} + \beta_2^{xf} IPI_t + \beta_3^{xf} PX_t^{f}/RX_t + \varepsilon_t^{xf}$
5-18	Exports of manufactured wood products of the pulp and paper industry	$X_t^{z} = \beta_1^{xz} + \beta_2^{xz} IPI_t + \beta_3^{xz} PX_t^{z}/RX_t + \varepsilon_t^{xz}$
5-19	Imports of manufactured wood products of the wood industry	$M_t^{w} = \beta_1^{mw} + \beta_2^{mw} C_t^{w} + \beta_3^{mw} PC_t^{w}/PM_t^{w} + \beta_4^{mw} CUR_t^{w} + \varepsilon_t^{mw}$
5-20	Imports of manufactured wood products of the furniture industry	$M_t^{f} = \beta_1^{mf} + \beta_2^{mf} C_t^{f} + \beta_3^{mf} PC_t^{f}/PM_t^{f} + \beta_4^{mf} CUR_t^{f} + \varepsilon_t^{mf}$
5-21	Imports of manufactured wood products of the pulp and paper industry	$M_t^{z} = \beta_1^{mz} + \beta_2^{mz} C_t^{z} + \beta_3^{mz} PC_t^{z}/PM_t^{z} + \beta_4^{mz} CUR_t^{z} + \varepsilon_t^{mz}$
5-22	Consumption price of manufactured wood products of the wood industry	$PC_t^{w} = \beta_1^{pcw} + \beta_2^{pcw} S_t^{w} + \beta_3^{pcw} PC_{t-1}^{w} + \varepsilon_t^{pcw}$
5-23	Consumption price of manufactured wood products of the furniture industry	$PC_t^{f} = \beta_1^{pcf} + \beta_2^{pcf} S_t^{w} + \beta_3^{pcf} PC_{t-1}^{f} + \varepsilon_t^{pcf}$
5-24	Consumption price of manufactured wood products of the pulp and paper industry	$PC_t^{z} = \beta_1^{pcz} + \beta_2^{pcz} S_t^{z} + \beta_3^{pcz} PC_{t-1}^{z} + \varepsilon_t^{pcz}$
5-25	Export price of manufactured wood products of the wood industry	$PX_t^{w} = \beta_1^{pxw} + \beta_2^{pxw} PX_{t-1}^{w} + \beta_3^{pxw} RX_t + \beta_4^{pxw} WEPI_t^{w} + \varepsilon_t^{pxw}$
5-26	Export price of manufactured wood products of the furniture industry	$PX_t^{w} = \beta_1^{pxw} + \beta_2^{pxw} PX_{t-1}^{w} + \beta_3^{pxw} RX_t + \beta_4^{pxw} WEPI_t^{f} + \varepsilon_t^{pxw}$
5-27	Export price of manufactured wood products of the pulp and paper industry	$PX_t^{z} = \beta_1^{pxz} + \beta_2^{pxz} PX_{t-1}^{z} + \beta_3^{pxz} RX_t + \beta_4^{pxz} WEPI_t^{z} + \varepsilon_t^{pxz}$
5-28	Import price of manufactured wood products of the wood industry	$PM_t^{w} = \beta_1^{pmw} + \beta_2^{pmw} PM_{t-1}^{w} + \beta_3^{pmw} PC_t^{w}/PC_{t-1}^{w} + \beta_4^{pmw} RX_t + \varepsilon_t^{pmw}$
5-29	Import price of manufactured wood products of the furniture industry	$PM_t^{f} = \beta_1^{pmf} + \beta_2^{pmf} PM_{t-1}^{f} + \beta_3^{pmf} PC_t^{f} / PC_{t-1}^{f} + \beta_4^{pmf} RX_t + \varepsilon_t^{pmf}$
5-30	Import price of manufactured wood products of the pulp and paper industry	$PM_t^{z} = \beta_1^{pmz} + \beta_2^{pmz} PM_{t-1}^{z} + \beta_3^{pmz} PC_t^{z}/PC_{t-1}^{z} + \beta_4^{pmz} RX_t + \varepsilon_t^{pmz}$
Variables, and paramters, are to be read as follows:	$\mathbf{PC_t^{z} = \beta_1^{pcz} + \beta_2^{pcz} S_t^{z} + \beta_3^{pcz} PC_{t-1}^{z} + \varepsilon_t^{pcz}}$ **(Equation 5-24)** PC_t^{z} : Consumption price of the manufactured wood products of the pulp and paper industry at time t β_1^{pcz}, β_2^{pcz}, β_3^{pcz} : Firts (Independent), second and third population parameter of the equation of price of consumption for the manufactured wood products of the pulp and paper industry, respectively. S_t^{z} : Supply (production) of manufactured wood products of the pulp and paper industry at time t PC_{t-1}^{z} : Consumption price of the manufactured wood products of the pulp and paper industry at time t-1 (i.e. lagged 1 period) ε_t^{pcz} : Disturbance stochastic term of the equation of price of consumption for the manufactured wood products of the pulp and paper industry at time t	

Table 5-2 Theoretical Behavioral Equations for UMW (sub)model of the CFSM-I, containing only variables (original or proxy) with available time series

Equation number	Equation name	Theoretical Behavioral Equation
5-41	Supply (Production) of unprocessed wood for the manufactured wood products industry & final consumption other than firewood from Forest Plantations	$S_t^{MWfprw} = \beta_1^{sMWfprw} + \beta_2^{sMWfprw} VAST_t^{MWfprw} + \beta_3^{sMWfprw} PS_t^{MWrw} + \varepsilon_t^{sMWfprw}$
5-42	Supply (Production) of unprocessed wood for the manufactured wood products industry & final consumption other than firewood from natural forest	$S_t^{MWnfrw} = \beta_1^{sMWnfrw} + \beta_2^{sMWnfrw} PS_t^{MWrw} + \beta_3^{sMWnfrw} L_t^{MWnfrw} + \varepsilon_t^{sMWnfrw}$
5-43	Supply (Production) of unprocessed wood for firewood from natural forest	$S_t^{FWnfrw} = \beta_1^{sFWnfrw} + \beta_2^{sFWnfrw} PS_t^{FWrw} + \beta_3^{sFWnfrw} L_t^{FWnfrw} + \varepsilon_t^{sFWnfrw}$
5-48	Consumption of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$C_t^{MWrw} = \beta_1^{cMWrw} + \beta_2^{cMWrw} S_t^{w} + \beta_3^{cMWrw} S_t^{f} + \beta_4^{cMWrw} S_t^{z} + \beta_5^{cMWrw} PC_t^{MWrw} + \varepsilon_t^{cMWrw}$
5-49	Consumption of unprocessed wood for firewood	$C_t^{FWrw} = \beta_1^{cFWrw} + \beta_2^{cFWrw} U_t + \beta_3^{cFWrw} PC_t^{FWrw} + \beta_4^{cFWrw} NR_t + \beta_5^{cFWrw} W_t + \beta_6^{cFWrw} Y_t + \beta_7^{cFWrw} i_t + \varepsilon_t^{cFWrw}$
5-50	Exports of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$X_t^{MWrw} = \beta_1^{xMWrw} + \beta_2^{xMWrw} IPI_t + \beta_3^{xMWrw} PX_t^{MWrw}/RX_t + \varepsilon^{xMWrw}$
5-52	Imports of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$M_t^{MWrw} = \beta_1^{mMWrw} + \beta_2^{mMWrw} C_t^{MWrw} + \beta_3^{mMWrw} PC_t^{MWrw} / PM_t^{MWrw} + \beta_4^{mMWrw} CUR_t + \beta_5^{mMWrw} VAST_t^{MWfprw} + \varepsilon^{mMWrw}$
5-54	Consumption price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$PC_t^{MWrw} = \beta_1^{pcMWrw} + \beta_2^{pcMWrw} S_t^{MWrw} + \beta_3^{pcMWrw} PC_{t-1}^{MWrw} + \varepsilon_t^{pcMWrw}$
5-55	Consumption price of unprocessed wood for firewood	$PC_t^{FWrw} = \beta_1^{pcFWrw} + \beta_2^{pcFWrw} S_t^{FWrw} + \beta_3^{pcFWrw} PC_{t-1}^{FWrw} + \varepsilon_t^{pcFWrw}$
5-56	Export price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$PX_t^{MWrw} = \beta_1^{pxMWrw} + \beta_2^{pxMWrw} PX_{t-1}^{MWw} + \beta_3^{pxMWrw} RX_t + \beta_4^{pxMWrw} WEPI_t^{w} + \varepsilon_t^{pxMWrw}$
5-58	Import priceof unprocessed wood for the manufactured wood products industry & final consumption other than firewood	$PM_t^{MWrw} = \beta_1^{pmMWrw} + \beta_2^{pmMWrw} PM_{t-1}^{MWrw} + \beta_3^{pmMWrw} PC_t^{MWrw} / PC_{t-1}^{MWrw} + \beta_4^{pmMWrw} RX_t + \varepsilon^{pmMWrw}$
Variables, and paramters, are to be read as follows:	**$PC_t^{MWrw} = \beta_1^{pcMWrw} + \beta_2^{pcMWrw} S_t^{MWrw} + \beta_3^{pcMWrw} PC_{t-1}^{MWrw} + \varepsilon_t^{pcMWrw}$ (Equation 5-54)** PC_t^{MWrw} : Consumption price of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, at time t β_1^{pcMWrw}, β_2^{pcMWrw}, β_3^{pcMWrw} : Firts (Independent), second and third population parameter of the equation of consumption price of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, repectively. S_t^{MWrw} : Supply (production) of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, at time t PC_{t-1}^{MWrw} : Consumption price of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, at time t-1 (i.e. lagged 1 period) ε_t^{pcMWrw} : Disturbance stochastic term of the equation of consumption price of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood, at time t	

Table 5-3 Subscripts and superscript used for theoretical behavioral equations of the CFSM-I

Superscripts	Description	Superscripts	Description
cf	of the equation of consumption of manufactured wood products of the furniture industry	pmMWrw	of the equation of imports price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood
cFWrw	of the equation of consumption of unprocessed wood for firewood	pmw	of the equation of imports price of manufactured wood products of the wood industry
cMWrw	of the equation of consumption of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	pmz	of the equation of imports price of manufactured wood products of the pulp and paper industry
cw	of the equation of consumption of manufactured wood products of the wood industry	pxf	of the equation of exports price of manufactured wood products of the furniture industry
cz	of the equation of consumption of manufactured wood products of the pulp and paper industry	pxFWrw	of the equation of exports price of unprocessed wood for consumption as firewood
f	(manufactured wood products of the) furniture industry	pxMWrw	of the equation of exports price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood
FWnfrw	unprocessed wood for firewood from the natural forest	rw	unprocessed wood (or raw wood)
FWrw	unprocessed wood for firewood	sf	of the equation of supply (production) of manufactured wood products of the furniture industry
mf	of the equation of imports of manufactured wood products of the furniture industry	sFWnfrw	of the equation of supply of unprocessed wood for firewood from natural forest
mMWrw	of the equation of imports of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	sMWnfrw	of the equation of exports price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood natural forest
mw	of the equation of imports of manufactured wood products of the wood industry	sw	of the equation of supply (production) of manufactured wood products of the wood industry
MW	Manufactured wood products	sz	of the equation of supply (production) of manufactured wood products of the pulp and paper industry
MWfprw	unprocessed wood for the manufactured wood products industry & final consumption other than firewood from forest plantations	w	wood industry
MWnfrw	unprocessed wood for the manufactured wood products industry & final consumption other than firewood from natural forest	xf	of the equation of exports of manufactured wood products of the furniture industry
MWrw	Unprocessed wood for the manufactured wood products industry & final consumption other than firewood	xFWrw	of the equation of exports of unprocessed wood for firewood
mz	of the equation of imports of manufactured wood products of the pulp and paper industry	xMWrw	of the equation of exports of unprocessed wood for the manufactured wood products industry & final consumption other than firewood
pcf	of the equation of consumption price of manufactured wood products of the furniture industry	xw	of the equation of exports of manufactured wood products of the wood industry
pcFWrw	of the equation of consumption price of unprocessed wood for firewood	xz	of the equation of exports of manufactured wood products of the pulp and paper industry
pcMWrw	of the equation of consumption price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	z	(manufactured wood products of the) pulp (Zellstoff in German) and paper industry
pcw	of the equation of consumption price of manufactured wood products of the wood industry	z	pulp (Zellstoff in German) and paper industry
pcz	of the equation of consumption price of manufactured wood products of the pulp and paper industry	**Subscripts**	**Description**
pmf	of the equation of imports price of manufactured wood products of the furniture industry	t	time

Table 5-4 List of variables, available time series, sources and units used for the CFSM-I

Variable abbreviation	Name of original (or proxy) variable	Variable superscript (group of products or market)	Consolidated time series that could represent the variable (1970-2018)	Units of the consolidated data	Sources of Data*
C	Consumption	MWrw	Intermediate consumption at purchaser's prices	2015 Thousand million COP	1
C	Consumption	w, z, FWrw	Intermediate+Final consumption at purchaser's prices	2015 Thousand million COP	1
C	Consumption	f	Intermediate+Final consumption+Gross Fixed Capital Formation (GFKF) at purchaser's prices	2015 Thousand million COP	1
C / Y	Normalized consumption	MWrw	Intermediate consumption at purchaser's prices / Gross disposable income	2015 Thousand million COP / 2015 Thousand million COP	2
C / Y	Normalized consumption	w, z, FWrw	Intermediate+Final consumption at purchaser's prices / Gross Disposable Income	2016 Thousand million COP / 2015 Thousand million COP	2
C / Y	Normalized consumption	f	Intermediate+Final consumption+Gross Fixed Capital Formation (GFKF) at purchaser's prices / Gross Disposable Income	2017 Thousand million COP / 2015 Thousand million COP	2
CT	Total consumption	rw	Intermediate+Final consumption at purchaser's prices	2015 Thousand million COP	1
CT	Total consumption	MW, WFP	Intermediate+Final consumption+Gross Fixed Capital Formation (GFKF) at purchaser's prices	2015 Thousand million COP	1
CUR	Capacity utilization rate	w, z, f, MW	Capacity utilization rate	Percentage	3
D	Demand	w, z, f, MWrw, FWrw	Demand at purchaser's prices	2015 thousand of million COP	1
DT	Total demand	MW, rw, WFP	Total demand at purchaser's prices	2015 thousand of million COP	1
HCS	Housing construction starts (Approved area for housing construction as proxy for HCS)		Approved area for housing construction	Thousand of square meters approved for construction	4
HCS / NHH	Nomalized housing construction starts		Approved area for housing construction / Households	Thousand of square meters approved for construction / Thousand households	2
i	Inflation		Consumer price index	Percentage	5
IPI	Global Industrial Production Index (US IPI as proxy for Global IPI)		US Industrial Production Index, Annual, Seasonally Adjusted	Unitless, 2015 = 1	6
K	Capital	w, f, z	Value of fixed assets in accounting books, at 31st of December	2015 Thousand million COP	8
K	Capital	w, f, z	Gross investment in Buildings and Structures	2015 Thousand million COP	8
K	Capital	w, f, z	Gross investment in Machinery and Equipment	2015 Thousand million COP	8
K	Capital	w, f, z	Gross investment in Machinery and Equipment + Buildings and Structures	2015 Thousand million COP	8
K	Capital	w, f, z	Value of Building and Structures, at 31st of December	2015 Thousand million COP	8
K	Capital	w, f, z	Value of Machinery and Equipment, at 31st of December	2015 Thousand million COP	8
K	Capital	w, f, z	Value of Machinery and Equipment + Building and Structures, at 31st of December	2015 Thousand million COP	8
L	Labor	w, f, z	Employment	Number	8
L	Labor (NR as proxy for Labor)	MWrw, FWrw	Rural population as proxy for Employment	Number	5
M	Imports	w, z, f, MWrw, FWrw	Imports at purchaser's prices	2015 Thousand million COP	1
MT	Total imports	MW, rw, WFP	Total imports at purchaser's prices	2015 Thousand million COP	1
N	Total Population		Total population (midyear estimates)	Thousand people	5
N / NHH	Normalized population		Total population / Households	Thousand people / Thousand households	2
NHH	Households		Households	Thousand	9
NR	Rural population		Rural population	Thousand	5
NR / N	Normalized rural population		Rural population / Total pupulation	Thousand people / Thousand people	2
NR / NHH	Normalized rural population		Rural population / Households	Thousand people / Thousand of households	2
PC (with superscript)	Consumption price	w, z, FWrw	Consumption price deflator (Weighted average for Intermediate and Final consumption) = Consumption in current values / Cosumption in constant values	Unitless, 2015 = 1	10
PC (with superscript)	Consumption price	f	Consumption price deflator (Weighted average for Intermediate, Final consumption and Gross Fixed Capital Formation) = Consumption in current values / Cosumption in constant values	Unitless, 2015 = 1	10
PC (with superscript)	Consumption price	MWrw	Consumption price deflator = Consumption in current values / Cosumption in constant values	Unitless, 2015 = 1	1
PC (without superscript)	Consumer's price index		Consumer price index	Unitless, 2015 = 1	11
PC / PC (with superscript)	Relative price of consumption	w, f, z, MWrw	Consumption price / Consumption price	Unitless, 2015 = 1 / Unitless, 2015 = 1	2
PC / PC (without superscript)	Relative price of consumption	w, z, FWrw	Consumption price / Consumer price index	Unitless, 2015 = 1 / Unitless, 2015 = 1	2
PC / Ph	Relative price of consumption	MWrw	Consumption price / Price of housing	Unitless, 2015 = 1 / Unitless, 2015 = 1	2
PC / Phcm	Relative price of consumption	w, f, MWrw	Consumption price / Price of housing construction materials	Unitless, 2015 = 1 / Unitless, 2015 = 1	2
PC / PM	Relative price of consumption	w, f, z, MWrw	Consumption price / Import price	Unitless, 2015 = 1 / Unitless, 2015 = 1	2
Ph	Price of housing		Used housing price index	Unitless, 2015 = 1	12
Phcm	Price of housing construction materials		Producer price index by economic destination or use: Construction materials	Unitless, 2015 = 1	12
PM	Import price	w, f, z, MWrw, FWrw	Import price deflator = Import in current values / Import in constant values	Unitless, 2015 = 1	10
PS	Supply price	w, f, z, MWrw, FWrw	Supply price deflator = Supply in current values / Supply in constant values	Unitless, 2015 = 1	10
PS / PS	Relative price of supply	MWrw, FWrw	Supply price / Supply price	Unitless, 2015 = 1 / Unitless, 2015 = 1	2
PX	Export price	w, f, z, MWrw	Export price deflator = Export in current values / Export in constant values	Unitless, 2015 = 1	10
PX / RX	Relative price of exports	w, f, z MWrw	Export price / Exchange rate	Unitless, 2015 = 1 / (USD/COP)	2
RX	Exchange rate		Official exchange rate (UMN per US$, average for a period) or Exchange rate, national currency (COP)/USD (market+estimated)	COP/USD	6
RX	Exchange rate		Exchange rate index - Calculated based on exchange rate of Federal Reserve Bank of St. Louis	Unitless, 2015 = 1	6

Sources: 1) DANE, Colombia's National Accounts Supply and Use Tables, base 1975, 1994, 2005 and 2015; (2) Calculated in this research; (3) Thoumi (1971) Study for National Department of Planning, Coyuntura Economica Journal (1972-1990) based on Fedesarrollo's Industrial Survey and Enterprise Opinion Survey (industrial Sector), and Fedesarrollo's Capacity utilization rate database (1991-2019) based on Fedesarrollo's Entrerprise Opinion Survey; (4) DANE, Construction licenses, 1970 - 2019; (5) World Bank, World Development Indicators; (6) Federal Reserve Bank of St. Louis; (7) DANE, Producer price index statistics; (8) DANE, Manufacturing Annual Survey; (9) DANE, Colombia's Household Survey (1970 - 1978), and Colombia's Households 1985-2005 Estimations and 2006-2020 Projections, 1979 - 1984 Estimations based on population by the author of this research; (10) Calculated based on DANE, Colombia's National Accounts Supply and Use Tables, base 1975, 1994, 2005 and 2015; (11) Colombia's Central Bank - Consumer's price index. Estimated base on CPI 2018-base (Dec 2018=100); (12) Central Bank of Colombia; Used Housing Price Index (IPVU)_Base 1990 = 100. 1.1.1. Nominal and real index - Total, by city, VIS and non VIS_annual periodicity and real estate prices in the housing market in Bogota 1970-2004 Samuel Jaramillo González (2004). CEDE Document 2004-42 ISSN 1657-7191 (Electronic Edition) October, 2004. https://www.academia.edu/7380909/Precios_inmobiliarios_de_vivienda_en_Bogot%C3%A1_1970-2013; (13) Estimated based on Several National Sources of Data and FAO; (14) DANE, DANE's Statistical Yearbook (1970-1975), DANE's historical time series 1976 -1983, 1984-2000, DANE Household Survey 2001-2017 and DANE's Website 2018; (15) Estimations based on VAS and multiple sources for forest plantations area and volume; (16) Estimated using SCRPFC and several national sources of forest plantations data; (17) Estimated using SCRPFC; (18) Federal Reserve Bank of St. Louis (for Capital Stock), Central Bank of Colombia (Public Debt and External Debt)

5.3 Final estimated behavioral equations of the CFSM-I

For selecting the final equations of the model, among the estimated equations, several criteria were followed as per Kant et al. (1996). Signs of variables in accordance with what is expected by economic theory and no first-order autocorrelation were the main criteria for selecting a final equation. For choosing among equations with alternative specifications (including those resulting from variables with more than one time series available), the additional conditions used in selecting the final equation were the adjusted-R^2 and statistical significance of individual variables. When first-order correlation was not corrected by applying Prais-Winsten (PW) and Cochrane-Orcutt (CO) methods, the OLS equation was retained for the model. As a consequence, the process of selecting the final equations of the CFSM-I was subject to compromises. The concessions were similar to the ones made by Kant et al (1996, p. 1123) in building the Canadian Forest Product Sector model (CFPSM): "accepting some equations that do not have a good statistical fit in order to build a complete structural model (Pindyck and Rubinfield 1991, p. 337) and sometimes dropping a variable that is insignificant or whose sign is inconsistent with what is expected in the theory." As in the case of the CFPSM, the CFSM-I final estimated equations summarized in tables 5-5 and 5-6 "should be seen as the result of considerable specification searching, and classical interpretations of econometrics may not fully apply."

For a better interpretation, in addition to the final estimated behavioral (regression) equations for both the UWM and MWM (sub)models of the CFSM-I, Tables 5-5 and 5-6 include the values of the t statistic, t statistic with robust standard errors (for OLS estimation), adjusted R^2, DW d or Dh (acceptable values between -1.64 and +1.64), rho (ρ) coefficient of first-order autocorrelation with t statistic on the right, and the standard error of the estimate divided by the mean of the dependent variable (SEE/MDV)[37]. Appendix 5-1 presents a detailed documentation of the process of parameter estimations. The estimations were conducted using IBM SPSS Statistics® 26. The appendix also shows all OLS, PW, and CO estimated equations for the behavioral equations of the CFSM-I. For final equations estimated by Prais-Winsten and Cochrane-Orcutt methods, OLS estimated equations are provided as a source of comparison.

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[37] As a general rule in hypothesis testing, if one gets a t-statistics bigger than 2, usually the null hypothesis (of randomness) can be rejected at the 0.05 level of significance. Also, as a general rule, values of DW d of 2 or close to this value are considered to signal no first-order autocorrelation of the disturbances.

Table 5-5 Final Estimated Behavioral Equations for the MWM (sub)model of the CFSM-I

Equation number	Equation name	Method of estimation	Description	Estimated Equation					
5-10	Supply (Production) of manufactured wood products of the wood industry	AR(1) CO - Cochrane-Orcutt method	Regression Equation	S_t^w =	2248.7461326	+ 1741.0367355 PS_t^w	+ 0.0066841 L_t^w	- 8816.7016208 PC_t^{MWrw}/P_t^{hcm}	
			t statistics		2.5	2.2	0.2	-0.2	
			t statistics with robust standard errors						
				Adjusted R^2 =	0.03	DW d = 1.7	Rho (AR1) = 0.92 14.0	SEE/MDV = 8.4%	
5-11	Supply (Production) of manufactured wood products of the furniture industry	OLS - Ordinary least squares	Regression Equation	S_t^f =	17.9182170	+ 4865.4819046 PS_t^f	+ 0.0793323 L_t^f	+ 0.3334932 K_t^f	- 430.913581 PC_t^{MWrw}/P_t^h
			t statistics		0.2	11.3	5.3	2.0	-1.8
			t statistics with robust standard errors		*0.1*	*6.1*	*3.3*	*2.2*	-0.9
				Adjusted R^2 =	0.99	DW d = 1.7		SEE/MDV = 6.6%	
5-12	Supply (Production) of manufactured wood products of the pulp and paper industry	AR(1) CO - Cochrane-Orcutt method	Regression Equation	S_t^z =	3870.9075320	+ 7358.1621388 PS_t^z	+ 0.0947103 L_t^z	+ 0.5908341 K_t^z	- 2179.316559 PC_t^{MWrw}/P_t^h
			t statistics		3.9	3.7	1.8	3.2	-1.9
			t statistics with robust standard errors						
				Adjusted R^2 =	0.70	DW d = 1.1	Rho (AR1) = 0.86 10.2	SEE/MDV = 5.4%	
5-13	Consumption of manufactured wood products of the wood industry	AR(1) PW - Prais-Winsten method	Regression Equation	C_t^w / Y_t =	0.00754967	- 0.09352710 PC_t^w/P_t^{hcm}	- 0.00009993 U_t	+ 0.00000075 HCS_t/NHH_t	
			t statistics		4.0	-0.6	-1.6	1.6	
			t statistics with robust standard errors						
				Adjusted R^2 =	0.07	DW d = 1.9	Rho (AR1) = 0.91 12.879	SEE/MDV = 8.2%	
5-14	Consumption of manufactured wood products of the furniture industry	AR(1) PW - Prais-Winsten method	Regression Equation	C_t^f / Y_t =	0.009505153	- 0.114112642 PC_t^f/P_t^{hcm}	- 0.000101239 U_t	+ 0.000000769 HCS_t/NHH_t	
			t statistics		3.6	-0.7	-1.4	1.4	
			t statistics with robust standard errors						
				Adjusted R^2 =	0.06	DW d = 1.3	Rho (AR1) = 0.95 17.983	SEE/MDV = 8.1%	
5-15	Consumption of manufactured wood products of the pulp and paper industry	AR(1) PW - Prais-Winsten method	Regression Equation	C_t^z / Y_t =	0.01381023	- 0.54708842 PC_t^z/PC_t	- 0.00011820 U_t	+ 0.00374694 N_t/NHH_t	
			t statistics		1.2	-1.8	-0.7	1.3	
			t statistics with robust standard errors						
				Adjusted R^2 =	0.00	DW d = 1.8	Rho (AR1) = 0.95 18.616	SEE/MDV = 5.9%	
5-16	Exports of manufactured wood products of the wood industry	AR(1) CO - Cochrane-Orcutt method	Regression Equation	X_t^w =	-47.2232115	+ 142.4008357 IPI_t	- 22739.3863258 PX_t^w/RX_t		
			t statistics		-1.1	3.5	-0.8		
			t statistics with robust standard errors						
				Adjusted R^2 =	0.29	DW d = 1.4	Rho (AR1) = 0.65 5.1348	SEE/MDV = 36.3%	
5-17	Exports of manufactured wood products of the furniture industry	AR(1) CO - Cochrane-Orcutt method	Regression Equation	X_t^f =	-94.7349542	+ 515.2883424 IPI_t	- 375985.6483349 PX_t^f/RX_t		
			t statistics		-0.6	2.6	-2.7		
			t statistics with robust standard errors						
				Adjusted R^2 =	0.19	DW d = 2.1	Rho (AR1) = 0.74 6.6423	SEE/MDV = 38.5%	
5-18	Exports of manufactured wood products of the pulp and paper industry	AR(1) PW - Prais-Winsten method	Regression Equation	X_t^z =	-41.3144894	+ 695.3970228 IPI_t	+ 551501.3181275 PX_t^z/RX_t		
			t statistics		-0.1	1.3	0.7		
			t statistics with robust standard errors						
				Adjusted R^2 =	-0.01	DW d = 1.4	Rho (AR1) = 0.95 18.394	SEE/MDV = 20.7%	
5-19	Imports of manufactured wood products of the wood industry	AR(1) PW - Prais-Winsten method	Regression Equation	M_t^w =	-85.89613705	+ 0.09839081 C_t^w	+ 302.75348214 PC_t^w/PM_t^w	- 0.44302215 CUR_t^w	
			t statistics		-0.6	2.6	2.4	-0.3	
			t statistics with robust standard errors			*928.8*			
				Adjusted R^2 =	0.39	DW d = 1.3	Rho (AR1) = 0.94 17.503	SEE/MDV = 25.1%	
5-20	Imports of manufactured wood products of the furniture industry	AR(1) PW - Prais-Winsten method	Regression Equation	M_t^f =	-216.40363890	+ 0.13100586 C_t^f	+ 91.01801982 PC_t^f/PM_t^f		
			t statistics		-1.7	5.7	1.6		
			t statistics with robust standard errors						
				Adjusted R^2 =	0.50	DW d = 1.9	Rho (AR1) = 0.95 19.094	SEE/MDV = 19.9%	
5-21	Imports of manufactured wood products of the pulp and paper industry	AR(1) PW - Prais-Winsten method	Regression Equation	M_t^z =	-770.1213975	+ 0.2335422 C_t^z	+ 923.8895191 PC_t^z/PM_t^z	- 5.8249830 CUR_t^z	
			t statistics		-1.9	18.2	4.6	-1.2	
			t statistics with robust standard errors						
				Adjusted R^2 =	0.89	DW d = 1.4	Rho (AR1) = 0.63 4.9062	SEE/MDV = 7.4%	
5-22	Consumption price of manufactured wood products of the wood industry	OLS - Ordinary least squares	Regression Equation	PC_t^w/PC_t =	0.0021974	- 0.00000016 S_t^w	+ 0.8330429 PC_{t-1}^w/PC_{t-1}		
			t statistics		2.4	-2.0	11.3		
			t statistics with robust standard errors		*2.2*	*-2.0*	*9.9*		
				Adjusted R^2 =	0.83	DW h = 2.0		SEE/MDV = 4.7%	
5-23	Consumption price of manufactured wood products of the furniture industry	OLS - Ordinary least squares	Regression Equation	PC_t^f/P_t^{hcm} =	0.0014464411	- 0.0000000803 S_t^f	+ 0.8957963334 PC_{t-1}^f/P_{t-1}^{hcm}		
			t statistics		1.7	-1.6	12.1		
			t statistics with robust standard errors		*1.5*	*-1.7*	*12.0*		
				Adjusted R^2 =	0.79	DW h = -1.2		SEE/MDV = 5.5%	
5-24	Consumption price of manufactured wood products of the pulp and paper industry	OLS - Ordinary least squares	Regression Equation	PC_t^z/PC_t =	0.005378794	- 0.000000183 S_t^z	+ 0.672400253 PC_{t-1}^z/PC_{t-1}		
			t statistics		3.6	-2.8	8.3		
			t statistics with robust standard errors		*3.6*	*-2.9*	*8.5*		
				Adjusted R^2 =	0.92	DW h = 0.6		SEE/MDV = 5.3%	
5-25	Export price of manufactured wood products of the wood industry	AR(1) PW - Prais-Winsten method	Regression Equation	PX_t^w =	-0.01795662	+ 0.36690977 PX_{t-1}^w	+ 0.00025066 RX_t	+ 0.10977207 $WEPI_t^w$	
			t statistics		-0.3	3.7	6.0	1.0	
			t statistics with robust standard errors						
				Adjusted R^2 =	0.98	DW h = 1.2	Rho (AR1) = 0.31 1.9414	SEE/MDV = 8.5%	
5-26	Export price of manufactured wood products of the furniture industry	OLS - Ordinary least squares	Regression Equation	PX_t^f =	-0.17124469	+ 0.67176581 PX_{t-1}^f	+ 0.00002664 RX_t	+ 0.40915616 $WEPI_t^f$	
			t statistics		-2.5	4.6	1.1	2.7	
			t statistics with robust standard errors		*-2.0*	*2.3*	*0.6*	*2.2*	
				Adjusted R^2 =	0.97	DW h = 2.7		SEE/MDV = 13.3%	
5-27	Export price of manufactured wood products of the pulp and paper industry	OLS - Ordinary least squares	Regression Equation	PX_t^z =	-0.101249006	+ 0.048753909 PX_{t-1}^z	+ 0.000281241 RX_t	+ 0.264386451 $WEPI_t^z$	
			t statistics		-5.7	0.7	12.9	6.5	
			t statistics with robust standard errors		*-4.4*	*0.5*	*10.9*	*5.1*	
				Adjusted R^2 =	1.00	DW h = 5.0		SEE/MDV = 5.6%	
5-28	Import price of manufactured wood products of the wood industry	AR(1) CO - Cochrane-Orcutt method	Regression Equation	PM_t^w =	0.0245559762	+ 0.5326640749 PM_{t-1}^w	+ 0.0307631699 PC_t^w/PC_{t-1}^w	+ 0.0001605137 RX_t	
			t statistics		0.2	5.1	0.27	4.9	
			t statistics with robust standard errors						
				Adjusted R^2 =	0.931	DW h = 0.91	Rho (AR1) = 0.48 3.2	SEE/MDV = 9.3%	
5-20	Import price of manufactured wood products of the furniture industry	AR(1) CO - Cochrane-Orcutt method	Regression Equation	PM_t^f =	-0.018876658	+ 0.537659381 PM_{t-1}^f	+ 0.010719018 PC_t^f/PC_{t-1}^f	+ 0.000193668 RX_t	
			t statistics		-0.3	10.8	0.2	10.3	
			t statistics with robust standard errors						
				Adjusted R^2 =	0.987	DW h = 0.89	Rho (AR1) = 0.52 3.6	SEE/MDV = 4.9%	
5-30	Import price of manufactured wood products of the pulp and paper industry	AR(1) PW - Prais-Winsten method	Regression Equation	PM_t^z =	-0.09146760	+ 0.37663883 PM_{t-1}^z	+ 0.07214532 PC_t^z/PC_{t-1}^z	+ 0.00022556 RX_t	
			t statistics		-1.1	3.8	1.12	8.0	
			t statistics with robust standard errors						
				Adjusted R^2 =	0.907	DW h = 1.11	Rho (AR1) = 0.77 7.2	SEE/MDV = 8.3%	

Table 5-6 Final Estimated Behavioral Equations for the UWM (sub)model of the CFSM-I

Equation number	Equation name	Method of estimation	Description	Estimated Equation									
5-41	Supply (Production) of unprocessed wood for the manufactured wood products industry & final consumption other than firewood from Forest Plantations	AR(1) PW - Prais-Winsten method	Regression Equation	S_t^{MWfprw} =	-3.2027099	+	16.2377453 $VAST_t^{MWfprw}$	+	415.7631690 PS_t^{MWrw}				
			t statistics		-0.04		2.2		2.0				
			t statistics with robust standard errors										
				Adjusted R^2 = 0.45			DW d = 1.4		Rho (AR1) = 0.90	12.406	SEE/MDV =	18.9%	
5-42	Supply (Production) of unprocessed wood for the manufactured wood products industry & final consumption other than firewood from natural forest	AR(1) CO - Cochrane-Orcutt method	Regression Equation	S_t^{MWnfrw} =	-201.7925567	+	467.0081259 PS_t^{MWrw}	+	0.0422465 NRt				
			t statistics		-0.2		5.4		0.4				
			t statistics with robust standard errors										
				Adjusted R^2 = 0.41			DW d = 1.9		Rho (AR1) = 0.74	6.7792	SEE/MDV =	12.2%	
5-43	Supply (Production) of unprocessed wood for firewood from natural forest	AR(1) CO - Cochrane-Orcutt method	Regression Equation	S_t^{FWnfrw} =	-1940.6284430	+	1.8886851 PS_t^{FWnfrw} / PS_t^{MWrw}	+	11690.3709618 NRt/Nt				
			t statistics		-2.6		0.0		3.5				
			t statistics with robust standard errors										
				Adjusted R^2 = -0.02			DW d = 0.9		Rho (AR1) = 0.94	16.823	SEE/MDV =	9.1%	
5-48	Consumption of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	AR(1) CO - Cochrane-Orcutt method	Regression Equation	C_t^{MWrw} /Yt=	0.0007846	+	0.1032182 S_t^{w} / Yt	+	0.0223671 S_t^{f}/ Yt	+	0.0196760 S_t^{z} / Yt	-	0.0191429 PC_t^{MWrw} / P_t^{hcm}
			t statistics		1.6		3.1		0.7		1.1		-0.8
			t statistics with robust standard errors										
				Adjusted R^2 = 0.36			DW d = 1.3		Rho (AR1) = 0.85	9.6971	SEE/MDV =	5.8%	
5-49	Consumption of unprocessed wood for firewood	AR(1) CO - Cochrane-Orcutt method	Regression Equation	C_t^{FWrw} / Yt =	0.0048151	-	0.0000283 Ut	-	0.0045057 PC_t^{FWrw}	+	0.0001756 NRt/NHHt		
			t statistics		2.2		-1.0		-3.4		0.1		
			t statistics with robust standard errors										
				Adjusted R^2 = 0.24			DW d = 1.1		Rho (AR1) = 0.92	14.596	SEE/MDV =	12.5%	
5-50	Exports of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	AR(1) CO - Cochrane-Orcutt method	Regression Equation	X_t^{MWrw} =	-31.9361609	+	53.8771424 IPI_t	+	20609.7204062 PX_t^{MWrw}/RX_t				
			t statistics		-2.3		2.5		0.9				
			t statistics with robust standard errors										
				Adjusted R^2 = 0.29			DW d = 1.5		Rho (AR1) =0.55	4.0639	SEE/MDV =	68.1%	
5-52	Imports of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	AR(1) PW - Prais-Winsten method	Regression Equation	M_t^{MWrw} =	0.5643122	+	0.0069777 C_t^{MWrw}	+	0.0405855 PC_t^{MWrw}/PM_t^{MWrw}	-	0.3547749 $VAST_t^{MWfprw}$		
			t statistics		0.3		1.3		0.1		-1.3		
			t statistics with robust standard errors										
				Adjusted R^2 = -0.06			DW d = 1.7		Rho (AR1) =0.46	3.1163	SEE/MDV =	-3.3%	
5-54	Consumption price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	OLS - Ordinary least squares	Regression Equation	PC_t^{MWrw} / P_t^{hcm} =	0.0042496	-	0.000000269 S_t^{MWfprw}	-	0.000002352 S_t^{MWnfrw}	+	0.728509717 PC_{t-1}^{MWrw}/P_{t-1}^{hcm}		
			t statistics		2.1		-0.4		-1.6		5.8		
			t statistics with robust standard errors		*1.7*		*-1.5*		*-1.5*		*7.6*		
				Adjusted R^2 =	0.87		DW h = 0.2				SEE/MDV =	6.4%	
5-55	Consumption price of unprocessed wood for firewood	OLS - Ordinary least squares	Regression Equation	PC_t^{FWrw} / PC_t=	0.00080659	-	0.00000077 S_t^{FWrw}	+	0.94778076 PC_{t-1}^{FWrw} / PC_{t-1}				
			t statistics		2.0		-2.0		27.4				
			t statistics with robust standard errors		*2.2*		*-1.8*		*23.0*				
				Adjusted R^2 =	0.95		DW h = 0.7				SEE/MDV =	5.1%	
5-56	Export price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	OLS - Ordinary least squares	Regression Equation	PX_t^{MWrw} =	-0.006795	+	0.889285 PX_{t-1}^{MWrw}	+	0.000050 RX_t				
			t statistics		-0.4		9.6		2.0				
			t statistics with robust standard errors		*-0.6*		*7.4*		*2.1*				
				Adjusted R^2 =	0.94		DW h = 1.6				SEE/MDV =	26.3%	
5-58	Import price of unprocessed wood for the manufactured wood products industry & final consumption other than firewood	OLS - Ordinary least squares	Regression Equation	PM_t^{MWrw} =	-0.0127863	+	0.2062113 PM_{t-1}^{MWrw}	+	0.0216517 PC_t^{MWrw} / PC_{t-1}^{MWrw}	+	0.0001909 RX_t		
			t statistics		0.0		1.2		0.0		2.9		
			t statistics with robust standard errors		*0.0*		*0.3*		*0.0*		*1.5*		
				Adjusted R^2 =	0.51		DW h =				SEE/MDV =	75.0%	

5.3.1 Supply side (Eq 5-10 to 5-12, and 5-41 to 5-43)

When estimating the Supply (Production) equations, several issues arose, and were mostly solved. Except for the equation explaining the supply of unprocessed wood for firewood (S^{FWnfrw}), which yielded an adjusted R^2 of 0.39, all OLS estimated regression equations for supply were a good fit (with adjusted R^2 varying from 0.77 to 0.99). However, the OLS estimates produced some coefficients with signs contrary to what was expected in economic theory and, except for the estimates for the S^f (Eq 5-11), all of them were subject to first-order autocorrelation of the disturbances (autocorrelation hereafter). When re-estimated by CO and PW methods, autocorrelation was corrected, as were most of the incorrect signs of the coefficients. Wrong signs for coefficients of PC^{MWrw} in estimates of supply for w, f and z (Eq. 5-10, 5-11 and 5-12), PS^{FWrw} and the proxy variable rural population (NR) in the equation of supply of FWrw (S^{FWrw}, Eq. 5-42), and K^w in Eq 5-10 were present even after the correlation was corrected.

The issue of obtaining the wrong signs for econometric estimations of price parameters in forestry has been reported by several authors, e.g. Singh and Nautiyal (1986) cited by Kant et al. (1996), Haynes (1993), and Kant et al. (1996). To overcome the issue of prices in this research, a similar approach to that of Kant et al. (1996), of using relative prices instead of absolute prices was tried. The ratio of PC^{MWrw} to housing construction materials (P^{hcm}) was used in the equation of S^w, while the ratio of PC^{MWrw} to price of housing (P^h) was applied in equations of S^f and S^z. For the equation of S^{FWrw}, the ratio of PS^{FWrw} to the price of supply of unprocessed wood for the manufactured wood forest product industry and final consumption other than firewood (PS^{MWrw}) was tried. All these relative prices resulted in price coefficients with the correct signs, without affecting the correct signs of the other variables obtained by the first OLS (for S^f), CO (for S^w, S^z, S^{MWnfrw} and S^{FWrw}) and PW (for S^{MWfprw}) estimates.

However, these new estimations did not correct the wrong signs for the coefficients of both NR (in the equation of S^{FWrw}) and K^w (in the equation of S^w). A new estimation for S^{FWnfrw} was done using the variable NR normalized by total population (N), and that try resulted in an equation free of autocorrelation, with all the correct signs. None of the multiple tries of applying OLS, CO and PW methods, which included using the seven times series available to represent K^w, gave an equation for S^w with a coefficient of K^w showing the expected sign (positive). As a result, the variable was dropped in that equation.

In summary, of the six final estimated equations for supply chosen for CFSM-I, one is an OLS estimate (S^f), four are autoregressive of first order (AR1) CO estimates (S^w, S^z, S^{MWnfrw} and S^{FWrw}), and one is an AR1 PW estimate (S^{MWfprw}). All six equations are free of autocorrelation. Although all estimated coefficients for all variables of the six equations have the correct signs, i.e., in agreement with economic theory, some coefficients are not different from zero at 5%, 10%, 15% or even larger levels of significance. Those coefficients are: labor for the wood industry (L^w) and relative consumption price of unprocessed wood (PC^{MWrw}/P^{hcm}) in the equation of S^w, rural population (NR) in the equation of S^{MWnfrw}, and the relative supply price of unprocessed wood for firewood (PS^{FWnfrw}/PS^{MWrw}) in the equation of S^{FWnfrw}.

All other estimated coefficients were significantly different from zero. The coefficient of the VAST (a key policy variable of CFSM-I) in equation for S^{MWfprw} (Eq 5-41) was statistically significant and different from zero at a 15% level of significance. The coefficient of the price of supply (PS) in all equations was also different from zero, but at levels of significance of 5% in the mentioned equation and in that of S^w (Eq 10), and 1% in equations of S^f (Eq 5-11), S^z (Eq 5-12) and S^{MWnfrw} (Eq 5-42). In Eq 5-11 and 5-12, the coefficients of capital and labor were also statistically significant and different from zero at levels < 7.5%. Finally, the coefficient for the proxy variable of labor (i.e., NR/N) used in the equation of supply of unprocessed wood for firewood (Eq 5-43) was different from zero at a level of significance of 0.1%.

The information of the first three paragraphs of this subsection accounts for the detailed process of estimation applied not only to the supply equations but to the rest of the behavioral regression equations, until reaching an appropriate estimated final equation. The explanation on the rest of the final estimated equations of tables 5-5 and 5-6 in the following subsections is omitted. Those interested in the details of the estimation process of each behavioral regression equation of the CFSM-I can refer to Appendix 5-1.

5.3.2 Demand side: Consumption (Eq 5-13, 5-14, 5-15, 5-48, and 5-49)

Instead of the absolute variables presented in the theoretical equations of consumption for w, f, z, MWrw and FWrw (Eq 5-13, 5-14, 5-15, 5-48 and 5-49, respectively), normalized variables and relative prices were necessary for obtaining adequate final estimated equations for the CFSM-I.

The normalization of variables was done, as per Kant et al. (1996), in order to achieve stationarity in time series data. For all five equations, the dependent variable of consumption was normalized by the value of national gross disposable income (Y). Y was also used to normalize the supply variables (Sw, Sf and Sz) in the equation of consumption of unprocessed wood for the manufactured wood products industry and rural uses other than firewood, C^{MWrw}, (i.e., Eq 5-48), a derived consumption equation. The number of households (NNH) was the normalizing variable of choice for the housing construction starts (HCS) and the total population, in equations 5-13 and 5-14, and 5-15, respectively. This variable was also used for normalizing the rural population in equation 5-49.

Relative prices were used to mitigate the issue of incorrect signs of the estimated coefficients obtained for the variable consumption price (PC) in the first round of estimations. Problems with incorrect signs of estimated coefficients for PC in equations of consumption were also reported by Kant et al (1996), and Singh and Nautiyal (1986), the latter authors cited by the former. Indeed, Kant et al. reported the PC as one of the most troublesome variables in forest products consumption estimates. In this research, the relative PC of w, f, and MWrw with respect to the price of housing construction materials (P^{hcm}) were used in equations of consumption of w, f, and MWrw (Eq 5-13, 5-14 and 5-48), while the ratio between PC^{z} and the average prices of consumption of Colombia's economy, i.e., the consumer price index (PC without any superscript) was used for equation 5-15, the consumption equation for manufactured wood products of the pulp and paper industry (C^{z}).

For tries using the normalized and relative variables described, OLS estimates obtained for all five equations of consumption were subject to autocorrelation, and as a result, all of them were subject to autocorrelation correction. Three PW estimates for C^{w}, C^{f} and C^{z} (Eq 5-13, 5-14 and 5-15, Table 5-5) and two CO estimates for C^{MWrw} and C^{FWrw} (Eq 5-48 and 5-49, Table 5-6) were included in the final CFSM-I; all five free of autocorrelation[38].

[38] Note that, for some of the estimated consumption equations (as well as other equations in tables 5-5 and 5-6), the value of DW d and Dh statistics are far from the acceptable values for declaring the equations free of autocorrelation, 2.0 and -1.64 to + 1.64, respectively. For some estimated equations, the calculation of Dh was not possible. As already commented in this section, a combination of these two statistics, graphical methods, and other tests such as the run test and the Breusch–Godfrey test were also used. The last three were used especially when the DW d value lied between the lower and upper limits (inconclusive evidence regarding the presence or absence of first-order serial correlation), or when calculating Dh was not possible. For a heuristic explanation on how tests for detecting first-order serial correlation work, refer to Gujarati and Dawn (2009).

In all estimated equations, signs of the coefficients agree with those expected by economic theory, however, only a few of them were statistically different from zero. Prices of consumption in equation of C^z and C^{FWrw} were different from zero at 7.5% and 0.1% levels of significance, respectively. For the remaining three equations, they were statistically significant from zero only at large levels (more than 20%), similar to the levels for the coefficients of unemployment (U) and N/NHH in the equation of C^z, S^f/Y and S^z/Y in the equation of C^{MWrw}, and NR/NHH in the equation of C^{FWrw}. Coefficients of HCS/NHH and U were different from zero at the 15% and 10% levels of significance in equations of C^f and C^w.

Interestingly, the coefficient of S^w/Y in the derivate equation of C^{MWrw} was statistically different from zero at a level of 0.3%. The fact that in this research only the normalized supply of manufactured wood products of the wood industry (S^w/Y) variable resulted statistically different from zero in this equation, seems to indicate that, in Colombia, the derivate consumption of unprocessed wood for the manufactured wood products industry and final consumption other than firewood is mostly driven by the performance of the Colombian wood industry, and a lot less by the performance of the Colombian pulp & paper industry. Lastly, it is marginally driven by the performance of the Colombian furniture industry (see the coefficients of equation 5-48 in Table 5-6).

Finally, the coefficients of inflation (i) and wealth (W) variables, which were included in the theoretical equations to be estimated, resulted with wrong signs in all estimation tries. Hence, the two variables were dropped from the final consumption equations.

5.3.3 Demand side: Exports (Eq 5-16, 5-17, 5-18, and 5-50)

Phase I of the CFSM only includes estimated behavioral regression equations for exports of w, f, z, and MWrw. It was not possible to estimate an export equation for unprocessed wood for firewood (X^{FWrw}), as no time series was available given that Colombia’s exports of this type of wood was negligible in the few years that it existed for the period 1975 - 2015.

OLS estimates of all four export equations were subject to autocorrelation. As with the other groups of equations mentioned above, these equations were re-estimated by CO and PW methods to correct for it. Re-estimated equation of X^z resulted in coefficients with an incorrect sign for either one or both variables, Global industrial production index (IPI) and the ratio of the export price of z to the exchange rate of COP/USD (PX^z/RX). PX^z/RX was not different from zero in all three equations (the autocorrelated OLS and the ones corrected by the PW and CO methods). Given that the coefficient of first order of autocorrelation was 0.95, the equation estimated by the PW was retained for equation of X^z (Eq 5-18). The re-estimated equation for X^w (Eq 5-16) obtained by CO method was superior to that yielded by the PW method, as such, the latter was included in the CFMS. For equations of X^f (Eq 5-17) and X^{MWrw}, (Eq 5-50), the CO method reported better estimates, hence, they were accepted for the model.

In equations 5-16, 5-17 and 5-50, the IPI coefficient was different from zero at the 2% significance level. On the other hand, the coefficient of PX/RX was only statistically different from zero in the equation of exports of furniture (X^f), at the 1% level. In the other three equations, it was different from zero only at significance levels > 40%. In equation 5-50 (X^{MWrw}), the sign of the coefficient for PX/RX was wrong, though non-significant.

5.3.4 Demand side: Imports (Eq 5-19, 5-20, 5-21, and 5-52)

Phase I of the CFSM also does not include an import equation for unprocessed wood for firewood (M^{FWrw}). The same reason as in the case of the export equation explained in subsection 7.3.3 applies to the import equation: no time series was available for estimation, because for most of the years in period 1975-2015, Colombia did not import firewood or wood charcoal.

OLS estimates for the imports of w, f, z, and MWrw equations (Eq 5-19, 5-20, 5-21 and 5-52, respectively) were subject to autocorrelation. When corrected for it, PW estimates resulted in a better fit than those obtained by CO. Therefore, the four import equations re-estimated by the PW method are the ones included in the model. For the equations of imports of manufactured wood products of the wood (forest) products industry, i.e., w, f, and z, the explanatory variable of consumption was different from zero at the 1.5% significance level. A second variable included in these equations, the relative price of consumption with respect to the price of imports (PC/PM) was statistically different from zero at the 2% level only in the equations of M^w (Eq 19) and M^z (Eq 5-21), and at the 10% level in M^f (Eq 5-20). The third variable included, the capacity utilization rate (CUR) of each of the Colombian industries producing w, f and z, was not different from zero in the import equation of w, had the incorrect sign in the import equation of f, and was different from zero at the 22% significance level for the import equation of z. CUR was kept in the equations of M^w and M^z, and it was dropped from M^f.

Regarding the import equation of unprocessed wood for the manufactured wood products industry and final consumption other than firewood - M^{MWrw} (Eq 5-52), the coefficient of the variable PC/PM was not statistically different from zero. In this equation, a fourth variable was included in the theoretical considerations, the $VAST^{MWfprw}$; the coefficient of this variable and that of the C^{MWrw} resulted different from zero at the 10% significance level.

5.3.5 Consumption prices (Eq 5-22, 5-23, 5-24, 5-54, and 5-55)

The equations of consumption prices had several issues. When estimated using the consumption prices (PC) in absolute terms, autocorrelation was present in the OLS estimates for the PC^f (Eq 5-23) and PC^z (Eq 5-24). OLS estimates for the equations of PCw (Eq 5-22), PC^{MWrw} (Eq 5-54), and PC^{FWWrw} (Eq 5-55) were not autocorrelated, but had coefficients with signs contrary to those expected by economic theory. The problem with signs was also present in the OLS autocorrelated estimates of Eq 5-24. When re-estimated applying CO and PW methods, only PC^f was free of autocorrelation, and maintained the correct coefficient signs.

Similar issues were reported by Kant et al. (1996). In keeping in line with their work, and being consistent with the strategy used to address the issue of prices in equations of consumption explained in subsection 5.3.2, relative prices were used instead of absolute prices. Ratios of price of consumption to the price of housing construction materials and to the consumer price were applied. This strategy resulted in all five estimated equations of consumption price being free of autocorrelation, and with the correct signs for the OLS estimates. As such, they were selected as final equations for the CFSM-I.

In all five estimated equations, coefficients of all variables were statistically different from zero. The coefficients of relative prices of consumption achieve this at levels of significance $< 0.01\%$, even when using the robust standard errors (which correct for heteroscedasticity[39]). This could be interpreted as empirical evidence of the sticky nature of prices of consumption in forestry in this research. Coefficients for Supply (National Production) of the respective group of products, the other variable included in all five equations for PC^{w}/PC, PC^{f}/PC^{hcm}, PC^{z}/PC and PC^{FWrw}/PC, are also different from zero at a level of significance < 10% (with robust standard errors).

In the equation for PC^{MWrw}/PC^{hcm} (Eq 5-54), supply is separated in both the value of supply from forest plantations (S^{MWfprw}), and that from the natural forest (S^{MWnfrw}). The OLS estimates result in a coefficient for S^{MWfprw} not different from zero (t statistic = - 0,4). Visual inspection and the Koenker–Bassett (KB) test showed that equation (5-54) is subject to heteroscedasticity of the residuals. With standard errors corrected by heteroscedasticity (i.e., using robust standard errors to calculate t), the t statistics of the OLS coefficient of S^{MWfprw} change to -1.5, i.e., different from zero at a level of significance of 15%, the same level at which S^{MWnfrw} is statistically different from zero (see equation 5-54 in table 5-6).

5.3.6 Export prices (Eq 5-25, 5-26, 5-27, and 5-56)

For all export price equations, all OLS estimated coefficients were consistent with the theory. However, equations for PX^{w} (Eq 5-25), PX^{f} (Eq 5-26) and PX^{z} (Eq 5-27) were subject to autocorrelation. When corrected using CO and PW methods, only the PW estimate for equation 5-25 was both not autocorrelated and with coefficients signs in agreement with economic theory. As a result, the CFSM Phase I includes two OLS equations of export price subject to autocorrelation, two equations free of autocorrelation, the one of PX^{MWrw} (Eq 5-56) obtained by the OLS method, and the one of PX^{w} estimated by the PW method. All coefficients of the accepted estimated equations have the correct signs and all OLS estimated equations accepted are subject to heteroscedasticity of the residuals. The explanatory variable World Export price Index of w ($WEPI^{w}$) used in equation 5-56 was dropped as the estimated coefficient was not in agreement with economic theory.

[39] "…heteroscedasticity does not destroy the unbiasedness and consistency properties of the OLS estimators, but they are no longer efficient, not even asymptotically (i.e., large sample size). This lack of efficiency makes the usual hypothesis-testing procedure of dubious value." Gujarati and Dawn (2009, p. 415)

Most of the variables included in the accepted equations of the price of exports are statistically different from zero at usual levels of significance. Lagged price of exports (PX_{t-1}) is different from zero at significance levels < 5% in the equations of PX^w, PX^f, and PX^{MWrw}. For equation of PX^z it is only statistically different from zero at high levels of significance (> 30%). Similarly, exchange rate (RX) was only different from zero at levels of significance < 1% for the equations of PX^w, PX^z and PX^{MWrw}. Finally, the corresponding coefficient of WEPI in the equations of PX^f and PX^z was statistically different from zero at levels of 5% and in the case of PX^w at a level of 30%. Note that all significance levels mentioned above correspond to those related to the t statistics values calculated with robust standard errors.

5.3.7 Import prices (Eq 5-28, 5-29, 5-30 and 5-58)

Estimated import price equations making it to the CFSM Phase I are a combination of AR (1) CO, AR (1) PW and OLS estimates. For equations of import prices of w - PM^w (Eq 5-28) and f -PM^f (Eq 5-29), the CO method corrected the autocorrelation, and gave all the correct signs and higher t statistics. For the equation of import price of z -PM^z (Eq 5-30), the equation obtained by the PW method was the best fit. OLS estimates for the equation of import price of MWrw -PM^{MWrw} (Eq 5-58) have the correct signs and are free of autocorrelation.

Import prices for products of the manufacture wood products industry (i.e., PMw, PMf and PMz) are highly dependent on their corresponding lagged prices (PM_{t-1}) and on the exchange rate (RX). For the three equations, estimated coefficients of these variables were different from zero at levels of significance < 1%. The other variable included in this equation, the relative price of the current consumption price to the one-period lagged consumption price (PC_t/PC_{t-1}) was not statistically different from zero in the first two equations, and different from zero only at a high level of significance (25%) in the latter equation.

For the import price equation of unprocessed wood for the manufactured wood products industry and other final consumption other than firewood (PM^{MWrw}), the exchange rate (RX) was the only variable statistically different from zero, but at a significance level of 15%. Note in Table 5-6 that this level of significance corresponds to the t statistics value calculated with robust standard error, as both visual inspection and Koenker–Bassett (KB) test showed that this equation is subject to heteroscedasticity of the residuals.

5.4 Estimated elasticities

The estimated coefficients of the multiple linear regression behavioral equations that make up the CFSM Phase I (presented in tables 5-5 and 5-6 and discussed in section 5.3), are known as partial regression or partial slope coefficients. In each equation, every slope coefficient measures the change in the mean of the dependent variable (DV), *E*(DV), per unit change in the corresponding explanatory variable (EV_n), holding the values of all other explanatory variables constant (Gujarati and Dawn 2009). Although valuable, these partial coefficients do not measure the relative importance of each explanatory variable the way elasticities can (Mckillop 1967, Kant 1996). For linear equations, elasticities can be derived from the partial regression coefficients. One way of doing this is by simply multiplying the estimated partial regression coefficients by the ratio of the means of the corresponding EV_n and the DV (Mckillop 1967, Gujarati and Dawn 2009). This method was used to estimate the elasticities of each explanatory variable of the estimated equations forming the CFSM-I. Point and the corresponding interval estimated elasticities, summarized in Table 5-7, are considered another contribution of this research for several purposes in economics, including the development of other approaches for forest sector modelling.

Table 5-7 Elasticities of Production, Consumption, Exports, and Imports of wood forest products in Colombia, and Prices of C, X and M

Eslasticity Group	Product Group	Variable abbreviation	Elasticity (Mean)	Min Elasticity	Max Elasticity
Elasticities of production (Supply)	manufactured wood products of the wood industry (w)	PS_t^{w}	0.246	0.002	0.720
		L_t^{w}	0.018	0.011	0.026
		PC_t^{MWrw}/P_t^{hcm}	0.044	0.032	0.057
	manufactured wood products of the furniture industry (f)	PS_t^{f}	0.717	0.007	1.669
		L_t^{f}	0.331	0.161	0.664
		K_t^{f}	0.031	0.005	0.105
		PC_t^{MWrw}/P_t^{h}	0.084	0.001	0.210
	manufactured wood products of the pulp and paper industry (z)	PS_t^{z}	0.487	0.008	1.158
		L_t^{z}	0.225	0.151	0.314
		K_t^{z}	0.340	0.042	1.954
		PC_t^{MWrw}/P_t^{h}	0.195	0.085	1.255
	unprocessed wood for the manufactured wood products industry & final consumption other than firewood from forest plantations (MWfprw)	$VAST_t^{MWfprw}$	0.408	0.085	1.255
		PS_t^{MWrw}	0.685	0.009	1.811
	unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood from natural forest (MWnfrw)	PS_t^{MWrw}	0.436	0.006	1.154
		NRt	1.045	0.997	1.077
	unprocessed wood for firewood from natural forest (FWnfrw)	$PS_t^{FWnfrw} / PS_t^{MWrw}$	0.003	0.003	0.004
		NRt/Nt	7.130	5.016	9.839
Elasticities of Consumption	manufactured wood products of the wood industry (w)	U_t	0.172	0.121	0.301
		HCS_t/NHH_t	0.125	0.065	0.167
		PC_t^{w}/P_t^{hcm}	0.130	0.101	0.151
	manufactured wood products of the furniture industry (f)	U_t	0.148	0.104	0.258
		HCS_t/NHH_t	0.109	0.057	0.146
		PC_t^{f}/P_t^{hcm}	0.166	0.124	0.208
	manufactured wood products of the pulp and paper industry (z)	U_t	0.059	0.042	0.104
		N_t/NHH_t	0.709	0.569	0.917
		PC_t^{z}/PC_t	0.323	0.218	0.510
	unprocessed wood for the manufactured wood products industry & final consumption other than firewood (MWrw)	S_t^{w} / Yt	0.415	0.233	0.686
		S_t^{f} / Yt	0.091	0.063	0.114
		S_t^{z} / Yt	0.200	0.156	0.263
		PC_t^{MWrw} / P_t^{hcm}	0.119	0.088	0.155
	unprocessed wood for firewood (FWrw)	PC_t^{FWrw}	0.690	0.011	2.048
		Ut	0.149	0.104	0.260
		NRt/NHHt	0.288	0.201	0.394

Eslasticity Group	Product Group	Variable abbreviation	Elasticity (Mean)	Min Elasticity	Max Elasticity	Significance	Significance with robust standar error
Elasticities of Exports	manufactured wood products of the wood industry (w)	IPI_t	2.302	0.972	3.632	0.001	
		PX_t^w/RX_t	-0.285	-1.031	0.461	0.444	
	manufactured wood products of the furniture industry (f)	IPI_t	2.158	0.490	3.826	0.013	
		PX_t^f/RX_t	-0.623	-1.099	-0.147	0.012	
	manufactured wood products of the pulp and paper industry (z)	IPI_t	0.846	-0.511	2.203	0.215	
		PX_t^z/RX_t	0.302	-0.518	1.122	0.461	
	unprocessed wood for the manufactured wood products industry & final consumption other than firewood (MWrw)	IPI_t	3.142	0.627	5.656	0.016	
		PX_t^{MWrw}/RX_t	0.232	-0.321	0.785	0.401	
Elasticities of Imports	manufactured wood products of the wood industry (w)	C_t^w	1.266	0.266	2.265	0.015	
		CUR_t^w	-0.176	-1.214	0.862	0.733	
		PC_t^w/PM_t^w	0.956	0.138	1.773	0.023	
	manufactured wood products of the furniture industry (f)	C_t^f	1.793	1.161	2.426	0.000	
		PC_t^f/PM_t^f	0.373	-0.090	0.835	0.111	
	manufactured wood products of the pulp and paper industry (z)	C_t^z	1.065	0.946	1.183	0.000	
		CUR_t^z	-0.271	-0.711	0.169	0.219	
		PC_t^z/PM_t^z	0.680	0.380	0.979	0.000	
	unprocessed wood for the manufactured wood products industry & final consumption other than firewood (MWrw)	C_t^{MWrw}	3.041	0.362	5.720	0.109	
		$VAST_t^{MWfprw}$	-2.301	-4.334	-0.268	0.106	
		$PC_t^{MWrw} / PM_t^{MWrw}$	0.027	-1.035	1.089	0.952	
Elasticities of Consumption Prices	manufactured wood products of the wood industry (w)	S_t^w	-0.036	-0.073	0.001	0.058	0.056
		PC_{t-1}^w/PC_{t-1}	0.831	0.683	0.980	0.000	0.000
	manufactured wood products of the furniture industry (f)	S_t^f	-0.020	-0.045	0.005	0.111	0.094
		PC_{t-1}^f/P_{t-1}^{hcm}	0.896	0.746	1.046	0.000	0.000
	manufactured wood products of the pulp and paper industry (z)	S_t^z	-0.086	-0.147	-0.024	0.008	0.007
		PC_{t-1}^z/PC_{t-1}	0.685	0.518	0.852	0.000	0.000
	unprocessed wood for the manufactured wood products industry & final consumption other than firewood (MWrw)	S_t^{MWnfrw}	-0.080	-0.181	0.022	0.122	0.130
		S_t^{MWfprw}	-0.006	-0.038	0.026	0.702	0.640
		$PC_{t-1}^{MWrw}/P_{t-1}^{hcm}$	0.731	0.473	0.988	0.000	0.000
	unprocessed wood for firewood (FWrw)	S_t^{FWrw}	-0.033	-0.065	0.000	0.049	0.088
		$PC_{t-1}^{FWrw} / PC_{t-1}$	0.962	0.891	1.033	0.000	0.000
Elasticities of Export Prices	manufactured wood products of the wood industry (w)	PX_{t-1}^w	0.351	0.157	0.544	0.001	
		RX_t	0.539	0.356	0.721	0.000	
		$WEPI_t^w$	0.142	-0.147	0.431	0.326	
	manufactured wood products of the furniture industry (f)	PX_{t-1}^f	0.627	0.348	0.907	0.000	0.027
		RX_t	0.083	-0.077	0.244	0.300	0.581
		$WEPI_t^f$	0.753	0.192	1.313	0.010	0.036
	manufactured wood products of the pulp and paper industry (z)	PX_{t-1}^z	0.046	-0.093	0.184	0.506	0.612
		RX_t	0.787	0.664	0.910	0.000	0.000
		$WEPI_t^z$	0.412	0.283	0.541	0.000	0.000
	unprocessed wood for the manufactured wood products industry & final consumption other than firewood (MWrw)	PX_{t-1}^{MWrw}	0.806	0.636	0.977	0.000	0.000
		RX_t	0.219	-0.004	0.442	0.054	0.043
Elasticities of Import Prices	manufactured wood products of the wood industry (w)	PM_{t-1}^w	0.506	0.305	0.707	0.000	
		RX_t	0.381	0.223	0.539	0.000	
		PC_t^w/PC_{t-1}^w	0.074	-0.491	0.639	0.792	
	manufactured wood products of the furniture industry (f)	PM_{t-1}^f	0.508	0.413	0.604	0.000	
		RX_t	0.506	0.406	0.605	0.000	
		PC_t^f/PC_{t-1}^f	0.028	-0.206	0.262	0.809	
	manufactured wood products of the pulp and paper industry (z)	PM_{t-1}^z	0.352	0.162	0.542	0.001	
		RX_t	0.697	0.519	0.874	0.000	
		PC_t^z/PC_{t-1}^z	0.221	-0.181	0.622	0.272	
	unprocessed wood for the manufactured wood products industry & final consumption other than firewood (MWrw)	PM_{t-1}^{MWrw}	0.189	-0.141	0.519	0.254	0.738
		RX_t	0.770	0.223	1.318	0.007	0.153
		$PC_t^{MWrw} / PC_{t-1}^{MWrw}$	0.087	-4.282	4.457	0.968	0.966

5.4.1 Elasticities of Supply (National Production)

In this research, all estimated elasticities of supply (production) of all six groups of products considered with respect (w.r.t.) to all variables, except for rural population, are inelastic. Elasticity of supply w.r.t. price of supply (PS), the only variable common to all six groups, was not statistically significant for unprocessed wood for firewood from the natural forest (FWnfrw). For the rest of the groups (w, f , z, MWfprw, and MWnfrw), it was significant at levels < 5% and varied between 0.246* and 0.717*[40].

The product supply of manufactured wood products of the wood, furniture and pulp and paper industries (i.e., w, f and z, respectively) w.r.t. to both employment (L) of these industries and the relative price of consumption of unprocessed wood (PC^{MWrw}/P^{hcm}) were not statistically significant for w. For f and z, these elasticities and the one w.r.t. capital (K) were significant at levels < 10%. The elasticity of supply w.r.t. L is less elastic for z (0.025*) than for f (0.331*) and the other way around w.r.t. K (0.031* for f vs. 0.340* for z). Supply w.r.t. PC^{MWrw}/P^{h} is also less elastic for f (-0.084*) than for z (-0.195*)[41].

With a value of 0.408, the elasticity of supply of unprocessed wood for the manufactured wood products industry & final consumption other than firewood from Forest Plantations (MWfprw) w.r.t. Total Volume of available stock of unprocessed wood for Supply at the beginning of a year from forest plantations ($VAST^{MWfprw}$), was only significant at a level of 15%. Finally, the product supply elasticity w.r.t. rural population (NR), the variable used as a proxy for employment in supplying MWnfrw and FWnfrw, was statistically significant only for the latter variable, and its value is the highest of all elasticities estimated in this research (7.130*).

In comparing the elasticities of supply presented in the previous three paragraphs, and the ones for consumption, imports, exports, and their respective prices obtained from the CFSM-I (discussed below), to those obtained from other studies, the warning by Buongiorno and Turner (2004) comes to mind. When estimating the own-price and income elasticities of import for most of the forest

[40]* Statistically different from zero at levels of significance equal or less than 10%, hereafter.

[41] Supply of f w.r.t. PC^{MWrw}/P^{h} results not significant if robust standard errors are used (see Table 5-7).

commodities, and compiling the published elasticities from different studies, they warned that "results of previous studies are difficult to compare because of differences in product definition, data sources, period covered, model form and estimation methods." Hence, for the elasticities obtained from the CFSM-I equations, the best source for comparison are the elasticities from the Canadian forest product sector model (CFPSM) by Kant et al. (1996), since their product definition, data sources and periodicity, model form and estimation methods are close to the ones in the CFSM-I. Elasticities from other studies are not directly comparable to the elasticities estimated for the CFSM-I, but still serve as reference for the reader.

With that in mind, when compared to elasticities estimated from both analogous models of the forest sector and other modelling approaches, the elasticities obtained from the CFSM-I are similar. Kant et al (1996) also found the supply of w, f and z supply w.r.t. the price of supply (0.21*, 0.04 and 0.14*, respectively) to be inelastic, though more inelastic than in this research (0.246*, 0.717* and 0.478*), especially for f and z. For these two product groups, the same study found their supply w.r.t capital inelastic as well (0.41*, and 0.14*, respectively), less inelastic for f and more inelastic for z if compared to the elasticities estimated here (0.031* and 0.340*).

Similarly, McKillop (1967), reported as inelastic the supply of lumber, plywood, and building paper and boards, paper, and paperboard (products aggregated under w and z) w.r.t their respective price: 0.8*, 0.4, 0.7, -0.1, 0.4*[42]. In his study, McKillop also reported as inelastic the lumber supply w.r.t. sawlog stumpage (-0.124*). As sawlog stumpage and prices of consumption of sawlogs are usually moving in the same direction and magnitude, the result of McKillop may serve as a benchmark for comparing the results of this research for supply of w w.r.t. PC^{MWrw} (-0.044).

Other studies have reported the supply of MWnfrw and MWfprw (the sum of them known as timber in other studies) w.r.t. prices of supply and w.r.t. $VAST^{MWfprw}$ (timber inventory) to be inelastic and of similar magnitudes as those in this research (0.436*, 0.685*, and 0.48, respectively).

[42] Sign for paper was wrong. Although the elasticity for separate products reported by McKillop is not the same as the elasticity for aggregate products under groups w and z, it is important to keep in mind that sawnwood, wood-based panels and paper and paperboard presented in Mckillop's study representant an important share of the products under w and z categories in this thesis. Hence, elasticities reported by McKillop may be interpreted as a benchmark for comparing the elasticities of w and z.

Buongiorno et al. (2003a, p 67) made a compilation of these elasticity estimates, and classified them in price elasticity (of timber, sawlogs, and pulpwood) and inventory elasticity. Of the 14 price elasticities of timber supply compiled, 11 were reported to vary from 0.24* to 0.95* (i.e., inelastic) and only three were reported equal or greater than 1*, i.e., elastic (Finland, Chile and New Zealand). In the same compilation, all four price elasticities of supply for sawlogs and pulpwood, and three out of four inventory elasticities reported were also inelastic. Elasticities for the first two vary from 0.55* to 0.61* and 0.23* to 0.74*, respectively, while for the latter from 0.13* to 0.76*.

Most recent compilations, Daigneault et al. (2016) and Borzykowski (2019), also report the short and long run price elasticities to be mostly inelastic for all types of wood (softwood, hardwood, pulpwood, sawlogs, etc.). In these reports, 31 out of 33 elasticities included varied from 0.06* to 0.97*. In all three compilations, separate elasticities of supply for planted forest and natural forest alike derived in this CFSM-I research are scarce. Morland et al. (2018) are one of these rare examples which include this separation, but only for the elasticity of supply w.r.t. prices. For industrial roundwood from natural forests (equivalent to MWnfrw), from planted forests (equivalent to MWfprw), and for fuelwood from both planted and natural forests (equivalent to FWnfrw), the study reported this elasticity being −0.1391 (non-significant), 0.226*, and −0.0150* (0.031* for domestic supply), respectively. Note that values obtained from the CFSM-I equations for the same elasticities are 0.436*, 0.685* and 0.003, respectively.

An apparent disagreement between the findings of Kant et al. (1996) and this research exist for the w, f and z supply levels w.r.t. employment. While Kant et al. found this relationship elastic (1.10*, 1.03* and 1.20* for w, f, and z respectively), this research obtained inelastic values (0.018, 0.331* and 0.225* for w, f, and z respectively). This research also found that relationship to be elastic for MWnfrw and FWnfrw supply w.r.t. rural population, the proxy variable for employment in supplying these two (group of) products (i.e., 1.045 and 7.130*, respectively).

The contradictory results for the w, f, and z may be explained by the difference between the Canadian forest industry (modelled by Kant et al.) and the Colombian one. In Colombia, there have been no important new investment initiatives to expand the installed capacity of the manufactured wood forest products industry in decades. As a result, this industry might have been operating close to the maximum level of labor needed to operate its capital (plants represented in machinery and equipment, and buildings and structures). In this case, an increase in the number of employees might not generate significant additional supply, hence the relationship of product supply w.r.t. employment is inelastic. This situation is more conspicuous in the wood industry, which has been characterized by low levels of investment since the 1970s (see Appendix 4-3). Note that the elasticity of supply w.r.t. labor is 0.018 for w, while for z and f the values are 0.225* and 0.331*, respectively.

In the case of the supply of unprocessed wood from the natural forest (FWnfrw and MWnfrw), small increases in rural population might have an important positive impact in the supply of these two products, as households in rural areas of Colombia still consume significant quantities of firewood for cooking and heating, and use the wood from the forest as a complementary source of income. Hence, the relationship between the supply of these products and the rural population, the proxy for employment, is elastic.

Finally, it is worth mentioning that data on elasticities of supply for forest products in Colombia in scientific literature is scarce. The 1.690 and 0.580 supply elasticities for fuelwood, industrial roundwood and other industrial roundwood w.r.t. price and forest stock, respectively, used for Colombia in the context of the Global Forest Products Model GFPM version 2017 (Buongiorno & Zhu 2020), are perhaps the only examples that can be found. The inelastic supply of the mentioned products w.r.t. price contradicts the findings in this research (0.436* for MWnfrw, 0.685* for MWfprw, 0.003 for FWrw), while the inelastic supply w.r.t. forest stock is close to the one estimated here (0.408 for $VAST^{MWfprw}$).

5.4.2 Elasticities of the demand side (Consumption, Exports, and Imports)

5.4.2.1 Elasticities of Consumption

Sixteen consumption elasticities for five groups of products (w, f, z, MWrw and FWrw) were estimated in this research, and all of them were inelastic. Half were not statistically different from zero, even at high levels of significance, such as 30%. Of the remaining eight, three relationships were statistically different from zero at levels of significance < 10%: the elasticity of consumption of z w.r.t. the ratio of prices of consumption of z to the general price of goods PC^z/PC (-0.323*), the elasticity of consumption of FWrw w.r.t. price of consumption of firewood PC^{FWrw} (-0.690*), and the elasticity of consumption of MWrw w.r.t. to the supply of w S^{w} (0.415*). The remaining five results were different from zero at levels ranging from 11% to 19%: the consumption elasticity of w w.r.t. unemployment U (-0.172) and housing construction HCS (0.125), the consumption elasticity of f w.r.t. U (-0.148) and HCS (0.109), and the consumption elasticity of z w.r.t. to population N (0.709).

The obtained elasticities indicate that U, HCS and PC^{w} are of almost equal importance to the consumption of w and f in Colombia, and N and PC^{z} are the most important determinants of the consumption of z. Similarly, the supply of w and z are the most important variables in the consumption of MWrw. This may stem from the fact that in Colombia MWrw is mostly used in the production of w, another important share of it to produce z, and a marginal quantity to obtain f. For consumption of FWrw, price is the most important determinant.

When compared to other studies, the findings of this research for the elasticities of consumption are similar. Kant et al. (1996) also reports an inelastic relationship for the consumption of w, f and z w.r.t. the following: price of consumption (-0.47*, -0.79* and -0.13* for w, f and z respectively), unemployment (-0.10*, -0.09* and -0.06* for w, f and z respectively), housing (0.19* and 0.16* for w and f respectively), and N (0.56* for z). Price inelastic domestic consumption and demand (usually defined as apparent consumption = production+imports-exports) have also been reported as inelastic, significant for levels < 5%, and ranging from 0.00* to -0.95* for most of the products aggregated under the w and z groups, as well as for roundwood (Simangunsong & Buongiorno 2001, Noce et al. 2010, Borzykowski 2019, Buongiorno 2019, Buongiorno and Zhu 2020, Skjerstad et al 2021, Schier et al. 2021, Buongiorno 2021).

Buongiorno (2021), and Buongiorno and Zhu (2020) provide the only existing data in scientific literature on the elasticity of domestic consumption and demand of forest products for Colombia. Table 5-8 and 5-9 summarize these estimations. The tables also include the elasticities of Colombia´s imports, domestic or local prices, and domestic supply; the latter already presented in subsection 7.4.1. All these elasticities were derived by said authors in the context of the GFPMX (a Cobweb Model of the Global Forest Sector), and in the framework of the Global Forest Product Model GFPM v. 2017 (a dynamic spatial partial equilibrium model), respectively. Given the level of aggregation and the way consumption is defined in the models, estimations for Colombia from the GFPMX (table 5-8) are a better benchmark for those obtained from the CFSM in this research.

As per this research's findings, the price elasticities of consumption from GFPMX were inelastic. However, those obtained from the estimated equations of the CFSM are always less inelastic than GFPMX's, for example -0.690* for FWrw vs -0.4043* for fuelwood. The way local prices are estimated in the two models may explain the differences between the GFPMX and CFSM estimates. While CFSM uses local prices of consumption obtained from the Colombian National Accounts, GFPMX estimates them as dependent on the world prices, which in turn depend on how much a country exports and imports. Dependency on world prices for estimating the local prices may not be the right assumption for the case of Colombia, as the country is not a big exporter or importer of some forest products. Hence, elasticities estimated in a similar style to GFPMX (and also GPFM) might not reflect the particularities of the Colombian forest products markets (see Appendix 4-3 for details on these markets).

One last interesting point is the comparison of elasticities of consumption of industrial roundwood w.r.t. the production of manufactured wood products. In the CFPMX, industrial roundwood consumption is a unitary elasticity, i.e., 1.0* (3rd row and 3rd column in Table 5-8). In the CFSM, it was estimated separately for the production of the groups of products modelled and the estimations were all inelastic, as follows: 0.415* for S^w, 0.091 S^f and 0.200 for S^z. Aggregation and overlooking the particularities of the national market for industrial roundwood in Colombia in the case CFPMX can help explain this difference.

Table 5-8 Elasticities and marginal propensity to export for forest products in Colombia, from GFPMX

Product	Elasticities					Marginal propensity to Export
	Consumption		Imports		Local price	
	Local Price	Shifter	Price	Shifter	World price	
Fuelwood[1]	-0.4043	0.1748	-0.0500	0.0177	1.0000	0.000000
Industrial roundwood[2]	-0.0500	1.0000	-0.0500	0.0000	1.0227	0.000465
Sawnwood[1]	-0.0665	0.0000	-0.0500	1.0000	-0.9397	-0.000006
Wood-based panels[1]	-0.2557	1.0000	-0.0501	1.0000	0.5910	0.000161
Wood pulp[3]	-0.0500	0.8309	-0.6507	1.0000	0.5910	0.000019
Paper and Paperboard[1]	-0.1595	0.4195	-0.0522	0.3264	0.7911	0.002774

Source: This research, based on data from Buongiorno (2021). [1]Shifter = gross domestic product; [2]Shifter = sawnwood, wood-based panel, and pulp production; [3]Shifter = paper and paperboard production. Elasticities were estimated with data from 1992 to 2018 in the context of GFPMX. The world price for each commodity group was the unit value of world exports, and the local price was the unit value of imports for net exporting countries, or the unit value of exports for net exporting countries. For countries with no imports or exports, the local price was the world price. Elasticities and marginal propensity were significant at levels < 1%.

Table 5-9 Elasticities for forest products in Colombia from GFPM

Comodity	Demand Eslasticities			Suppy elasticities	
	price	GDP	time trend	price	Shifter[1]
Fuelwood and charcoal	-0.059	0.018	1.000	1.690	0.580
Industrial roundwood				1.690	0.580
Other industrial roundwood	-0.059	0.018	1.000	1.690	0.580
Sawnwood	-0.410	0.692	1.000		
Veneer and plywood	-0.756	0.822	1.000		
Particleboard	-1.077	0.769	1.000		
Fiberboard	-1.020	1.122	1.000		
Mechanical wood pulp					
Chemical and semi-chemical wood pulp					
Other fiber pulp				1.000	0.140
Waste paper				1.000	0.670
Newsprint	-0.545	0.705	1.000		
Printing and writing paper	-1.149	0.809	1.000		
Other paper and paperboard	-0.700	0.575	1.000		

Source: This research, based on data from Buongiorno and Zhu (2020). [1]Shifter for wood primary products is Forest Stock in Colombia. Shifter for other fiber pulp and wastepaper is Colombia's GDP. Demand elasticities for 1992-2016 dynamic model pooled with long-run trend. Supply industrial roundwood elasticities for 1992-2016 were pooled. The GFPM has a supply equation for each country and primary product. In GFPM 2017, the primary products are fuelwood, industrial roundwood, other industrial roundwood, other fiber pulp, and recycled paper. The GFPM has demand equations by country and end product. In GFPM 2017, the end products are sawnwood, veneer & plywood, particleboard (including OSB), fiberboard, newsprint, printing & writing paper, and other paper and paperboard. Apparent consumption (production + import - export) = final demand, or intermediate demand (for input used by other products). Local price = world price plus transport cost (for net importers), or = world price (for net exporters). Manufacturing cost = price of output minus cost of wood or fiber inputs, given the price of output and inputs, and the input-output coefficients. Waste paper production ≤ waste paper recoverable. All elasticities were statistically significant at levels < 1%.

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5.4.2.2 Elasticities of exports

Exports of w, f, and MWrw were elastic w.r.t. the US industrial production index (IPI), the variable used as a proxy for the global production index (IPI), while for z it was inelastic (0.864), and different from zero only at a 22% significance level. The corresponding elasticities of 2.302*, 2.158* and 3.142* for w, f and MWrw were different from zero for levels of significance < 10%. In contrast, exports were inelastic w.r.t. the ratio between the export price of each product and exchange rate (PX^j/RX). Only in the case of f, this elasticity was different from zero at a significance level < 10% (-0.623*). The elasticities for w, z and MWrw (-0.285, 0.302 and 0.232, respectively) were not statistically different from zero even at large levels of significance, such as 40%.

The relationships of exports w.r.t. IPI and PX^j/RX reported by Kant et al. (1996) were similar to the findings in this research. In their study, the values of elasticities of exports w.r.t. IPI for w and f, and z were relatively close to the values found in this research, 2.04* vs 2.302*, 2.38* vs 2.158*, and 0.99* vs 0.846. The same study reported the elasticities of exports of w, f and z w.r.t. PX^j/RX as follows: 0.44*, 0.99* and 0.29*, respectively; all of them less inelastic than the ones found in this research.

Other elasticities of exports w.r.t. prices for separate forest products, such as sawnwood, wood-based panels, pulp, paperboard, etc., have been reported in scientific literature. Similar to what was presented in all the former subsections, these estimates are not directly comparable to the elasticities estimated for the CFSM, but can still serve as reference.

Nanang (2010) found the elasticity of exports w.r.t. price of exports to be elastic for sawnwood and plywood (2.849* and 1.796*), and inelastic for veneer (-0.8). He also found the exports of sawnwood w.r.t. exchange rates elastic for sawnwood (1.422*), and inelastic for plywood (-0.367*) and veneer (-0.413*). The -0.08 elasticity of export of veneer w.r.t. its price was interpreted by Nanang (2010) as “suggesting a ‘‘luxury effect’’ whereby consumers actually consume slightly more veneer as the price increases, rather than a shift to substitute products. The characteristics of veneer that enhance its decorative features for furnishing are unique to each species and hence more difficult to substitute than sawnwood or plywood.”

Karikallio et al. (2011) found that export demand for paper and cardboard w.r.t. own price was elastic (varying from 1.05* to 1.48*, subject to the model used for estimation), while the export demand for pulp w.r.t. own price was a mix of elastic and inelastic results, depending on the model used for the estimation (the fixed and random effect model elasticity varying between 0.41 and 0.63, and around 1.5 in the pooled OLS).

Finally, when considering the elasticities of exports derived from the export equations of the CFSM, one must keep in mind that, between 1970 and 2018, Colombia was a modest or even null exporter of unprocessed and manufactured wood forest products (see Appendix 4-3). Time series of exports and price of exports used to derive the export equation parameters for MWrw, w, f and z change abruptly for some of the years of the series, and it could have affected the estimated equation parameters. As a consequence, the elasticities of exports w.r.t. export price resulted, except for f, all not different from zero. Colombia's considerably low marginal propensities to export forest products (last column of table 5-8) can be considered as support for this analysis.

5.4.2.3 Elasticities of imports

Imports of w, f, z, and MWrw w.r.t. the consumption (C^j) of the respective product were elastic (1.266*, 1.793*, 1.065* and 3.041*), while those w.r.t to the ratio between the respective product consumption and import prices (PC^j/PM^j) were inelastic (0.956*, 0.373, 0.680*, 0.027). Also inelastic were the imports of w and z w.r.t. the capacity utilization rate (CUR^j) of the wood industry and pulp and paper industry (-0.176 and -0.271), as well as the imports of MWrw w.r.t. the volume stock in forest plantations, $VAST^{MWfprw}$(-2.301*). Except for the elasticity of imports w.r.t. PC^f/PM^f for the f, which was different from zero at the significance level of 11%, the elasticities of imports of manufactured wood products w.r.t. relative prices PC^j/PM^j and the ones w.r.t. C were all different from zero, at significance levels of less than 10%. For imports of MWrw (unprocessed wood) only the relationship w.r.t. $VAST^{MWfprw}$ was different from zero, at the 10% level of significance.

Compared to other studies, a mix of similarities and differences can be found. Kant et al (1996) also found the relationship of imports w.r.t. C to be elastic for w, f, and z groups (1.25*, 2.14* and

1.16*), but found the relationship of imports w.r.t. PC^j/PM^j in the case of furniture to be inelastic (0.72*). The same study also found inelastic the imports of w and z w.r.t. CUR^j (0.12* and 0.45*).

As in the case of exports, other elasticities of imports w.r.t. prices for separated forest products, such as unprocessed wood (roundwood, sawlogs, pulpwood), sawnwood, wood-based panels, pulp, paperboard, etc., have been reported in scientific literature. Examples of these elasticities can be found in Niquidet and Tang (2013), Sun (2014), Sun (2017), Zhang et al. (2017), Sun and Zhou (2018) and Muhammad and Jones (2021) for China's imports of roundwood, log, lumber and wood-based panels w.r.t. import prices, Buongiorno (2018) for US and Canada and the world impots of software lumber and newsprint w.r.t. import prices, Assogba (2021) for US softwood plywood imports w.r.t. own-price, Adewuyi et al. (2021) for Africa's imports of sawnwood w.r.t. own prices and exchange rates, Buongiorno and Turner (2004), Michinaka et al. (2011) and Buongiorno (2021) for several countries and the majority of forest commodities.

Buongiorno and Turner (2004) summarized the long-run own-price and income elasticities of import for most of the forest commodities before producing their estimations, based on several methods and 1970-1987 annual data for 64 countries. The elasticities compiled varied substantially for the same group of products (commodities). For those obtained with annual data (as in this research) the elasticities were between inelastic (-0.54) to elastic (-1.68) for wood, inelastic (-0.21 to 0.64) for sawnwood, elastic (-2.01 and -2.61) for plywood, elastic (-1.67) for veneer, inelastic (-0.48 and -0.83) for furniture, inelastic (-0.88 and 0.55) and elastic (-12.05 and -4,72) for pulp/waste paper and newsprint respectively, inelastic (-0.56 to 0.99) for paper products, and inelastic (-0.49 and 0.50) for other paper products[43]. The study of Turner and Buongiorno (2004) found the following long-run elasticities of imports w.r.t. (import) prices: roundwood -0.74, sawnwood -0.49*, plywood/veneer -0.81*, particleboard -0.70*, fibreboard – 1.53*, chemical pulp -0.48, recovered paper 0.01, newsprint -0.50*, printing and writing paper -1.20* and other paper and paperboard -0.74.

Elasticities of imports for Colombia were found only in the cobweb model of the global forest sector, GFPMX (Buongiorno, 2021). The relationship of imports w.r.t. to own price were inelastic

[43] Turner and Buongiorno did not report the significance level of the elasticities compiled.

and around -0.05* for fuelwood, industrial roundwood, sawnwood, wood-based panels and paper and paperboard, and -0.65* for wood pulp. Imports w.r.t. to other shifters (GDP, production of sawnwood, wood-based panels and paper and paperboard) ranged from 0.00* to 1.00* (Table 5-8).

5.4.3 Elasticities of prices of consumption, exports, and imports

The prices of consumption, exports, and imports of all five groups of products w.r.t. all variables included were inelastic.

Consumption prices w.r.t. supply (national production) S^j, were different from zero at significance levels of less than 10% for w, f, z and FWrw. For MWrw, this relation was only different from zero for the supply of unprocessed wood from forest plantations (S^{MWfprw}) at a level of significance of 13%, while for the supply of unprocessed wood from natural forest (S^{MWnfrw}) it was not different from zero even at the level of 60%. Prices of consumption w.r.t. one period lagged relative prices of consumption PC_{t-1}^j/PC_{t-1} or $PC_{t-1}^j\ /P_{t-1}^{hcm}$ were statistically different from zero at significance levels of less than 0.1%. Between using normal or robust standard errors, the significance was almost the same.

Elasticities for export prices of w, f, z and MWrw were mixed, in relation to the statistical significance and the use of robust standard errors for its calculation. Exports of w, f and MWrw w.r.t. one-lagged export price (PX_{t-1}^j) were different from zero at levels of significance < 5%, if normal standard errors or robust standard errors were used. With respect to real exchange rate (RX in COP/USD), exports were significantly different from zero at levels less than 10% for w, z and MWrw. Lastly, exports w.r.t. US Producer Price Index by Commodity as a proxy for Global world export price Index ($WEPI^j$) differed from zero only for the manufactured wood products of the furniture industry and the pulp and paper industry (at a level of significance < 0.1%).

Elasticities of w, f and z imports w.r.t. both the one-period lagged import price (PM_{t-1}^j) and the exchange rate (RX) were different from zero at levels of significance < 0.1%. For MWrw, the former elasticity was only significantly different from zero at the large level of 25% (using the normal standard error, which was lower than the robust one) and the latter one was statistically significant at a 15% level (using the robust standard error, which was bigger than the normal one). Import prices of all four products w.r.t. the ratio of consumption prices (PC_t^j / PC_{t-1}^j) were not different from zero.

Table 5-10 compares the elasticities of prices obtained from the equations estimated for the CFSM with the ones obtained in the CFPSM by Kant et al (1996). Elasticities of consumption prices for w, f and z derived in the CFPSM are inelastic, as are those derived in the CFSM. Also, the magnitude of the values of these elasticities from both models are relatively close. However, in the CFPSM, only the elasticities of consumption price w.r.t. to prices were significantly different from zero.

Elasticities of export prices w.r.t. US producer price index (the proxi for WEPI in the CFSM-I) and US Wholesale prices in the CFPSM for w were not significant in any model. Also, in both models, the estimated elasticities of export prices w.r.t. to the one-period lagged price of exports were inelastic and significant for w and f, although they were less elastic in the CFSM-I. With respect to exchange rates, export prices were inelastic and significantly different from zero for w and z in both models.

Finally, the import prices of w, f and z w.r.t. their one-period lagged import prices and exchange rates were different from zero. While the relationship of the import price w.r.t. the one-period lagged import price was inelastic in both models, the import price w.r.t. exchange rate was elastic in CFPSM and inelastic in the CFSM-I.

Table 5-10 Elasticities of prices for CFSM-I vs Canadian Forest Product Sector Model

Eslasticity Group	Product Group	Colombian Forest Sector Model CFSM				Canadian Forest Product Sector Model CFPSM (Kant et al. 1996)[1]
		Variable abbreviation	Elasticity (Mean)	Significance with normal standar errors	Significance with robust standar error	Elasticity (Mean)
Elasticities of Consumption Prices	manufactured wood products of the wood industry (w)	S_t^w	-0.036	0.058	0.056	-0.090
		PC_{t-1}^w/PC_{t-1}	0.831	0.000	0.000	0.74*
	manufactured wood products of the furniture industry (f)	S_t^f	-0.020	0.111	0.094	-0.050
		PC_{t-1}^f/P_{t-1}^{hcm}	0.896	0.000	0.000	0.79*
	manufactured wood products of the pulp and paper industry (z)	S_t^z	-0.086	0.008	0.007	-0.010
		PC_{t-1}^z/PC_{t-1}	0.685	0.000	0.000	0.99*
	unprocessed wood for the manufactured wood products industry & final consumption other than firewood (MWrw)	S_t^{MWnfrw}	-0.080	0.122	0.130	Not estimated (N.E.)
		S_t^{MWfprw}	-0.006	0.702	0.640	N.E.
		$PC_{t-1}^{MWrw}/P_{t-1}^{hcm}$	0.731	0.000	0.000	N.E.
	unprocessed wood for firewood (FWrw)	S_t^{FWrw}	-0.033	0.049	0.088	N.E.
		PC_{t-1}^{FWrw}/PC_{t-1}	0.962	0.000	0.000	N.E.
Elasticities of Export Prices	manufactured wood products of the wood industry (w)	PX_{t-1}^w	0.351	0.001		0.88*
		RX_t	0.539	0.000		0.96*
		$WEPI_t^w$	0.142	0.326		0.040
	manufactured wood products of the furniture industry (f)	PX_{t-1}^f	0.627	0.000	0.027	0.87*
		RX_t	0.083	0.300	0.581	2.68*
		$WEPI_t^f$	0.753	0.010	0.036	0.030
	manufactured wood products of the pulp and paper industry (z)	PX_{t-1}^z	0.046	0.506	0.612	0.80*
		RX_t	0.787	0.000	0.000	1.68*
		$WEPI_t^z$	0.412	0.000	0.000	0.040
	unprocessed wood for the manufactured wood products industry & final consumption other than firewood (MWrw)	PX_{t-1}^{MWrw}	0.806	0.000	0.000	N.E.
		RX_t	0.219	0.054	0.043	N.E.
Elasticities of Import Prices	manufactured wood products of the wood industry (w)	PM_{t-1}^w	0.506	0.000		0.82*
		RX_t	0.381	0.000		2.49*
		PC_t^w/PC_{t-1}^w	0.074	0.792		2.20*
	manufactured wood products of the furniture industry (f)	PM_{t-1}^f	0.508	0.000		0.86*
		RX_t	0.506	0.000		1.87*
		PC_t^f/PC_{t-1}^f	0.028	0.809		1.83*
	manufactured wood products of the pulp and paper industry (z)	PM_{t-1}^z	0.352	0.001		0.90*
		RX_t	0.697	0.000		1.28*
		PC_t^z/PC_{t-1}^z	0.221	0.272		0.720
	unprocessed wood for the manufactured wood products industry & final consumption other than firewood (MWrw)	PM_{t-1}^{MWrw}	0.189	0.254	0.738	N.E.
		RX_t	0.770	0.007	0.153	N.E.
		$PC_t^{MWrw}/PC_{t-1}^{MWrw}$	0.087	0.968	0.966	N.E.

[1] For the Canadian Model the authors used U.S. Wholesale price index. For the CFSM U.S. Producer price index was used for WEPI. * Different from zero at levels of significance less than 10%.

5.5 Model Validation

The CFSM-I validation involves the comparison between the values of all endogenous variables predicted by the model and their actual values (aka historical values or observations). This comparison allows for knowing "the magnitude of forecasting error that may result from using the model (Haitovisky et al. cited by Kant et al. 1996). Forecasting error is a means to judge the predictive ability of the estimated CFSM which, in turn, is useful for evaluating the suitability of the CFSM for explaining and forecasting the sectoral behavior, and for conducting scenario analysis of the Colombian forest sector.

To evaluate the predictive ability of the CFSM-I, it was simulated over different time horizons. Following Fair (1986) and Pindick & Rubinfield (1998), the simulations executed were grouped into *ex post* simulation (aka *historical* simulation) and *ex post* forecast[44]. An *ex post* simulation/forecast "is one in which the actual values of exogenous variables are used" (Fair 1986). The *ex post* simulations covered the period 1977-2015, while *ex-post* forecasts were run only for the years 2015 to 2018. The *ex post* simulations start in 1977, as it is the first year of the period (i.e., 1975-2015) with complete historical data for the endogenous and exogenous variables needed as initial conditions to simulate (i.e., solve or run) the CFSM[45]. *Ex post* forecast was only possible until 2018, since, at the time the forecast was executed[46], this was the last year with available forest sector data from National Accounts of Colombia needed for the simulation of the CFSM-I.

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[44] For readers who might not be familiar with the terminology of models, in the context of this research the definition of *simulation* is close to that of Pindick & Rubinfield (1998 p. 332): "the mathematical solution of a simultaneous set…of equations". For the CFSM-I, this simultaneous set comprises 50 behavioral equations and identities. Also, in this research the expressions "*simulate, simulating, run or solving*" a model are synonyms. The simulation process, which can be performed for one year or a period of years is done by the means of the software application for running the CFSM-I.

[45] Some variables of the estimated equations of the CFSM-I by Cochrane-Orcutt and Prais–Winsten methods need two-period lagged variables.

[46] According to Pindick and Rubinfield (1998 p. 336) "Forecasting involves a simulation of the model forward in time beyond the estimation period." Estimation period is "the time bounds over which the equations of a hypothetical model are estimated" Pindick and Rubinfield (1998 p. 335). For the CFSM Phase I, the estimation period is 1975-2015.

Measures of economic forecast accuracy

The simulated/forecasted (aka in general terms as *predicted or forecasted*) values of the endogenous variables resulting from the simulations were compared to their actual values using two of the four "most common measures of economic forecast accuracy" Buturac (2022): Theil's inequality coefficients U_1 (Theil 1958) and U_2 (Theil 1966). Those are relative measures of the third most common measure of economic forecast accuracy: the root mean squared error (rmse). To better understand the sources of the relative values of the rmse considered under U_1 and U_2, the decomposition of these statistics into the proportions of the bias (U^m), the variance (U^s) and the covariance (U^c) proposed by Theil (1958, 1966) was utilized. In addition, and following Kant et al. (1996), forecasted and actual values were also compared using the correlation coefficient (R) between them.

The third and fourth most common measures of economic forecast accuracy, the mean absolute error (mae) and the rmse, and the unscaled mean relative absolute error (UMBRAE) proposed by Chen et al. (2017) were also computed, in order to compare forecasted and actual values. In addition to the U^m, U^s, and U^c, the alternative Theil´s inequality decomposition into the proportions of the bias (U^m), new regression (U^r) and disturbance (U^d) (Theil 1958, 1966) were computed to have additional insight on the sources of the rmse used in obtaining U_1 and U_2.

As stated by Buturac (2022), a "common feature of most of the measures for the analysis of economic forecast accuracy [e.g. mae and rmse] is their poor resistance to outliers and scale-dependency". Chen et al. (2017) claimed that UMBRAE avoids both limitations.

Formulae and interpretation of measures

In the simulation/forecast context, the error e for any period t (e_t) can be defined as the actual (observed or historical) value of a variable of interest Y minus its predicted value Y_t^p, i.e., $e_t = Y_t - Y_t^p$, this absolute difference value is scale-dependent; to make it scale-independent, e_t is divided by the actual value Y_t, hence $p_t = (e_t / Y_t)$, p_t is then the simulation/forecast relative error in its ratio form, which can also be expressed in percentage, i.e., $p_t = (e_t / Y_t)100$ (Hyndman & Koehler 2006).

In consequence, the following are the formulae of simulation/forecast error expressed in absolute differences and relative differences: *rmse* = $\sqrt{mean(e_t^2)}$, and *mae* = *mean*($|e_t|$), root mean square percentage error *rmspe* = $\sqrt{mean(p_t^2)}$ and mean absolute percentage error *mape* = *mean*($|p_t|$), the lower their values the better (Buturac 2022, based on Hyndman & Koehler 2006).

The Theil's U_1 and U_2 statistics (aka the alternative specifications of Theil's U inequality coefficient) are relative measures for forecast accuracy (Buturac 2022). Both measure the proportionality of how equal two series of a variable of interest that are compared ($Y_t{}^p$ and Y_t) are, using the definition of the rmse relative to square root of the mean square successive differences of the actual values (rmssdav) in the case of U_2 and the sum of both the rmssdav and the root mean square successive differences of the forecasted values (rmssdfv) for U_1. The latter is computed as U_1=$\sqrt{1/n \sum_{t=1}^{n}(P_t - A_t)^2} / (\sqrt{\frac{1}{n}\sum_{t=1}^{n}(P_t)^2} + \sqrt{\frac{1}{n}\sum_{t=1}^{n}(A_t)^2}$) (Theil 1958 p. 32) while the former as U_2 = $\sqrt{\sum_{t=1}^{n}(P_t - A_t)^2} / \sqrt{\sum_{t=1}^{n}(A_t)^2}$ (Theil 1966 p. 28), where A_t, P_t "stand for a pair of predicted and observed changes" (Theil 1966 p. 28). For the numerical examples used by Theil in their books these changes were defined as $A_t = ((Y_t - Y_{t-1})/Y_{t-1})100$ and $P_t = ((Y_t{}^p - Y_{t-1})/Y_{t-1})100$ (Theil 1958 p. 58 and Theil 1960 p. 31, 32).

A caveat about A_t, P_t in Theil´s notation is important for beginners in econometric modelling. If the values of each period of the series compared are in absolute or relative changes (i.e., values of A_t, P_t are already in changes -as in the numerical examples of Theil, e.g. the A_{1993} and P_{1993} are 10 billion dollar and 12 billion dollar of GDP increase with respect to 1992 or the A_{1993} and P_{1993} are the GPD rate of $grow_{1993-1992}$ of 2% and 5%, respectively), U_1 and U_2 must be calculated with the values of the series already expressed in changes; no computations of A_t, P_t using the last two formulas of the preceding paragraph are needed. If the series compared are expressed in levels of each year (e.g. the A_{1992}, P_{1992} and A_{1993}, P_{1993} are 100, 100, 110 and 112 billion dollar of GDP each year) one must compute At and Pt using the two formulas of the preceding paragraph in absolute terms (i.e., $A_t = (Y_t - Y_{t-1})$ and $P_t = (Y_t{}^p - Y_{t-1})$). If the numerator of U_1 and U_2 in both cases (of values of the series compared) are expressed in absolute/relative changes or in levels, there is no need of calculations for A_t and P_t. Note that the numerator of these statistics is the same, the (i.e., the rmse, which uses only values of $Y_t{}^p$ and Y_t).

U_1 will always take values in the interval (0,1) while U_2 will fall between 0 and no upper bound. "If $U_1 = U_2 = 0$ simulated value = actual value for all t, and there is a perfect fit", if $U_1 = U_2 = 1$, the simulation of a model conduces to the same rmse as naïve no-change extrapolation; given that U_2 has no upper limit, it allows for cases worse than naïve no-change extrapolation, and it is considered superior than U_1 for measuring forecast accuracy (Kant et al. 1996). Hence, for any $U_2 > 1$, the simulated values of the variable of interest Y *(*i.e., $Y_t{}^p$*)* using the particular model under evaluation are, on average, worse than if one simply uses a model stating that $Y_t{}^p = Y_{t-1}$ for all t[47].

The bias (U^m), variance (U^s), and covariance (U^c) proportions of Theil's inequality U_1 (or U_2) which sum up to 1 "are useful as a means of breaking the simulation error down into its characteristic source" (Pindick & Rubinfield 1998). Granger & Newbold (1973) and Pindick & Rubinfield (1998) gave, respectively, the following formulas (sourced from Theil's 1966 book) and explanations for these proportions:

a) $U^m = (\bar{P} - \bar{A})^2/((1/n)\sum_{t=1}^{n}(P_t - A_t)^2)$ is an indicator of systematic bias as it measures how much the sample means of the predicted values $\bar{P}$ and actual values $\bar{A}$ of the variable of interest deviate from each other, which is expected to be close to zero,

b) the $U^s = (S_P - S_A)^2/((1/n)\sum_{t=1}^{n}(P_t - A_t)^2)$, where S_P, S_A are the sample standard deviation of the predicted values P_t and actual values A_t of the variable of interest, is an indication of the ability of the model under evaluation "to replicate the variability in the variable of interest". Large values of U^s signal high vs low fluctuation in the actual and simulated series, respectively, or vice versa,

c) $U^c = 2\,(1 - r)S_P S_A/((1/n)\sum_{t=1}^{n}(P_t - A_t)^2)$, where r is the sample correlation coefficient between predicted values P_t and actual values A_t of the variable of interest, is a measure of unsystematic error, i.e., the "remaining error after deviation from average values have been accounted for" which is a less worrisome part of the simulation error. "For any of U>0, the ideal distribution of the inequality over the three sources is $U^m = U^s = 0$ and $U^s = 1$."

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[47] Theil (1966, p. 28) give the following explanation "in words" for a numerical example when U_2 takes a value of 0.63: "The RMS [root mean square] prediction error of that example is 63% of the RMS error that would have been observed if the forecaster had confined himself to no-change extrapolation"

Granger & Newbold (1973) presented the formulae (also sourced from Theil's 1966 book) and a short explanation for the alternative decomposition in bias U^m (same as presented above), new regression U^r and disturbance U^d proportions (advocating for using this decomposition instead of the one presented above) as follows:

$U^r = (S_P - rS_A)^2/((1/n)\sum_{t=1}^{n}(P_t - A_t)^2$ and $U^d = (1 - r^2)S_A^2/((1/n)\sum_{t=1}^{n}(P_t - A_t)^2)$

For any good predictor the means of the P and A should be approximately equal, and the standard deviation of P should be very close to the standard deviation of A times the correlation coefficient between P and A. Hence, "U^m and U^r tend to zero for the optimum predictor and so U^d should tend to unity."

U^m and U^d of this alternative decomposition have the same interpretation as U^m and U^s in the first decomposition presented above. U^m and U^d are, respectively, the proportions of the forecast error "arising from systematic under- or over-estimation of the mean of the variable being forecasted" and "that is random" (Alburg 1984). On the other hand, U^r is "the slope of the relationship between the actual value of the series and its forecast value" (Alburg 1984).

Finally, according to Chen et al. (2017):

UMBRAE=MBRAE/(1-MBRAE), MBRAE $= 1/n\sum_{t=1}^{n}\frac{|e_t|}{|e_t| + |e_t^*|}$, and *BRAE*$= \frac{|e_t|}{|e_t| + |e_t^*|}$,

where $e_t^* = Y_{t-1} - Y_t$ for the one-step naïve method when it is used as benchmark. BRAE will have a maximum error of 1 if $|e_t^*| = 0$ and a minimum error of 0 if $|e_t| = 0$. For the especial case that both $|e_t^*|$ and $|e_t|$ are zero BRAE is defined as 0.5. Because of the upper bound an accuracy measure based on BRAE is most resistant to forecasting outliers. This measure is also more appropriate for intermittent data which have many zero-valued observations. Regarding UMBRAE, when it is equal to 1, the method of forecasting under evaluation performs roughly equal to the benchmark method; if UMBRAE < 1, the evaluated method performs roughly (1-UMBRAE)*100 better than the benchmark method; and, if UMBRAE>1 the evaluated method performs roughly (1-UMBRAE)*100 worse than the benchmark method.

For the rest of section 5.5 the R, and U_1, U_2 and their decomposition into U^m, U^s, and U^c are used to validate the CFSM Phase I. Readers interested in the rmse, mae and other measures cited in the preceding paragraphs can refer to Appendix 5-2. A good guide for beginners on the subject of economic forecast accuracy measures is Buturac (2022).

5.5.1 *Ex post* (*historical*) simulations

Three *ex post* simulation (covering 1977-2015) were carried: one for separately validating each individual estimated equation pertaining to the CFSM-I, one for validating those equations in the context of each of the five partial equilibrium (sub)models representing variables w, f, z, MWrw and FWrw in isolation, and one for validating the same equations interacting in all the five markets connected, i.e., the CFSM-I as an aggregated market. For the last two validations, a non-clearing and clearing situation of the markets were tested.

5.5.1.1 Forecast accuracy for individual equations in isolation

In validating separately each individual estimated equation, the values of the measures R, U_1 and U_2 shown in Table 5-11 indicate that most of the equations perform relatively well. Except for equations 5-52 and 5-58, imports (0.59) and price of imports (0.73) of unprocessed wood for the manufactured wood products industry & final rural consumption other than firewood (MWrw), all correlation coefficients R between the forecasted (P) and actual (A) series are considered high. High positive values of R does not imply perfect forecasting, but it signals the presence of an almost exact linear relation with positive slope between individual predictions P_t and the actual values A_t, an expected characteristic of a good forecasting[48]. The relatively low R for equations 5-58 and 5-52 may be attributed to the outliers in the historical data for both the prices and quantities of imports of MWrw which affect the computation of R, an statistics that is known for not being robust. Notice in Table 5-11 that for all equations the means of P and A do not differ much from each other.

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[48] For more details see Theil 1958, chapter II. A specific explanation of R in the context of forecast accuracy is found in pages 31 and 32.

On the other hand, U_1 statistic, varying between 0.17 for the import price of furniture industry products PM^f (Eq 5-29) and 0.64 for the PM^{MWrw} (Eq 5-58), indicates that all equations are acceptable in their performance. Though far from a perfect forecast, most of the equations (24 out of 32) at the very least have a value of U_1 less than halfway from perfect forecast. However, as indicated by the U_2 statistic (ranging from 0.35 for Eq of PM^f to 1.45 for the equation of C^{FWrw}, i.e., equation 5-49 - Consumption of unprocessed wood for firewood C^{FWrw}), two of the 32 behavioral equations making up the CFSM-I perform equal or worse than the naïve no-change extrapolation method of forecasting: Equation of X^z (Eq 18, exports of pulp & paper industry products) and C^{FWrw}, respectively. Note that for those equations in Table 5-11 with U_2 values less than 1, the root mean square prediction error (rmse) varies between 35% and 95% of the rmse that would have been observed if one would have chosen the naïve no-change extrapolation method to forecast.

Regarding the sources of origin for the simulation/forecast error, values on Table 5-11 indicate that none of the 32 behavioral equations of the CFSM-I have serious issues. U^m (varying between 0 for PM^f and 0.029 for C^{MWrw}) indicates no issues of systematic bias, i.e., the average of the predicted changes does not deviate importantly from the average of the realized changes, relative to the rms simulation/forecast error (Theil 1966, p. 32).

U^s, ranging from 0.00001 for supply of furniture industry products S^f to 0.378 for imports of wood industry products M^w, also indicates not serious issues for the equations in replicating the variability (fluctuations) of their corresponding actual series. Note in table 5-11 that after the equations of M^w, the equations exhibiting the highest U^s are those of the markets of MWrw and FWrw (e.g. C^{MWrw}, M^{MWrw}, C^{FWrw}, X^{MWrw}, PM^{MWrw}). These results are due to the inability of the estimated equations in forecasting well the outliers and “breaks” presented in the actual data from which those equations were estimated (see the graphical output in Appendix 5-1 and 5-2).

Finally, U^c values (0.62 to 0.99) show that, in all equations of the CFSM the rms simulation/forecast error comes from the unsystematic error. As commented by Theil (1958, 1996), Granger & Newbold (1973), Kant et al. (1996) and Pindick & Rubinfield (1998), this proportion of the forecast error is less worrisome, as it is unrealistic to expect that forecast and actual values be exact to each other, and a modeler (or forecaster) can do nothing about this imperfection. Alternative estimated equations for those with the worst U_2 and U^m and U^s were checked but none performed better than those initially selected, shown in Tables 5-5 and 5-6, and whose performance measures are presented in table 5-11.

Table 5-11 Measure of performance for Individual Behavioral Equations of the CFSM-I - Equations validated in isolation

Eq Number	Variable	R	U_1	U_2	U^m	U^s	U^c	Mean A	Mean P
10	S_t^w	0.984	0.47	0.90	0.00003	0.00092	0.99905	2 501.72	2 500.74
13	C_t^w	0.991	0.44	0.93	0.01666	0.10062	0.88272	2 346.51	2 370.78
16	X_t^w	0.899	0.54	0.86	0.00025	0.08920	0.91054	46.69	46.94
19	M_t^w	0.990	0.41	0.82	0.00001	0.37832	0.62167	184.84	184.96
22	PC_t^w	0.999	0.25	0.49	0.00019	0.03999	0.95982	0.3812	0.3809
25	PX_t^w	0.994	0.31	0.62	0.00013	0.00156	0.99831	0.5609	0.5604
28	PM_t^w	0.991	0.36	0.69	-	0.00485	0.99515	0.5076	0.5076
11	S_t^f	0.996	0.36	0.61	0.00157	0.00001	0.99842	3 025.76	3 018.54
14	C_t^f	0.997	0.30	0.62	0.00417	0.02120	0.97464	3 115.46	3 105.23
17	X_t^f	0.906	0.45	0.87	0.00226	0.11510	0.88264	176.20	179.14
20	M_t^f	0.985	0.35	0.71	0.01543	0.03985	0.94472	230.13	235.35
23	PC_t^f	0.999	0.27	0.60	0.00049	0.00292	0.99659	0.4558	0.4554
26	PX_t^f	0.986	0.50	0.81	0.00038	0.01302	0.98660	0.3863	0.3872
29	PM_t^f	0.999	0.17	0.35	-	0.00163	0.99837	0.4615	0.4615
12	S_t^z	0.996	0.36	0.73	0.00057	0.06459	0.93483	6 582.48	6 590.12
15	C_t^z	0.994	0.40	0.84	0.00822	0.03969	0.95209	7 616.72	7 654.34
18	X_t^z	0.979	0.52	1.00	0.01604	0.07148	0.91247	627.19	612.07
21	M_t^z	0.990	0.34	0.59	0.00027	0.00089	0.99884	1 672.36	1 670.52
24	PC_t^z	0.998	0.30	0.56	0.00269	0.00035	0.99696	0.4289	0.4301
27	PX_t^z	0.998	0.19	0.36	0.00138	0.00701	0.99161	0.4314	0.4322
30	PM_t^z	0.996	0.26	0.52	0.00007	0.03241	0.96752	0.3908	0.3911
41	S_t^{MWfprw}	0.981	0.45	0.94	0.00031	0.12832	0.87137	286.71	285.78
42	S_t^{MWnfrw}	0.967	0.52	0.95	0.00004	0.04702	0.95294	413.53	413.83
48	C_t^{MWrw}	0.995	0.36	0.71	0.02985	0.27668	0.69347	671.99	663.95
50	X_t^{MWrw}	0.894	0.59	0.87	0.02511	0.15778	0.81711	11.90	13.05
52	M_t^{MWrw}	0.597	0.58	0.87	0.00074	0.25823	0.74103	1.83	1.75
54	PC_t^{MWrw}	0.996	0.36	0.73	0.00731	0.00999	0.98270	0.4056	0.4079
56	PX_t^{MWrw}	0.969	0.49	0.88	0.00000	0.01604	0.98395	0.2753	0.2754
58	PM_t^{MWrw}	0.730	0.64	0.79	0.00000	0.15395	0.84605	0.2991	0.2987
43	S_t^{FWnfrw}	0.986	0.43	0.84	0.00089	0.01065	0.98846	485.16	483.95
49	C_t^{FWrw}	0.967	0.61	1.45	0.00108	0.18772	0.81119	494.09	491.60
55	PC_t^{FWrw}	0.999	0.24	0.51	0.00286	0.00042	0.99671	0.3541	0.3550

5.5.1.2 Forecast accuracy for individual equations interacting in the CFSM-I´s isolated market

In validating the equations for the isolated markets of the CFSM-I, i.e., w, f, z, MWrw and FWrw, two situations of each market are possible: Clearing and Non-Clearing. Recall that each market of the CFSM-I is represented by a partial equilibrium (sub)model having several behavioral equations (7 for the w, f, and z (sub)models, 8 for MWrw (sub)model and 3 for the FWrw (sub)model), 1 or more summation identities and one identity for the MCC[49]. Also bear in mind that CFSM-I can be used as a whole unit (i.e., all markets connected, see section 5.5.1.3) or market by market (i.e., by isolated market). When the CFSM-I is used for isolated markets, each (sub)model works independently from the others, and the variables that connect a sub(model) to one or several other (sub)models (i.e., S^w, S^f, S^z , PC^{Mwrw} and PS^{Mwrw}) are "inactive" and treated as exogenous variables[50].

For the market non-clearing situation (Non-MCC), identities of summation and of clearing condition are absent in each (sub)model. As a consequence of not having a clearing identity, the PS for every (sub)model is treated as an exogenous variable. For validation purposes, values of PS are the actual values for each market and no statistics of performance are calculated. For the market clearing situation (MCC), i.e., when the clearing identity is present and the market clearing condition holds, all adjustments to force the clearing are made to the PS. As a result of these adjustments, a new series of forecasted PS is available to compare with their actual values. This forecasted series of PS in each market and the measures of performance derived from them are key results obtained from the CFSM-I as explained later.

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[49] Behavioral equations for each market were summarized in tables 5-5 and 5-6. Summation and clearing identities for each market were presented in tables 3-2 and 3-4.

[50] "Inactive" in the context of the CFSM-I means that no interactions are allowed between (sub)models, i.e., solutions for each (sub)model are found independently. In other words, for any particular year, solutions of one (sub)model do not affect other solutions of other (sub)models. In this case, S^w, S^f, S^z , PC^{Mwrw} are termed as "connecting variables determined exogenously" if they appear on the right-hand side of any equation in any (sub)model of the CFSM-I. If these variables appear on the left-hand side of any equation of any (sub)model, they are just term endogenous variables.

The case of PS^{MWrw} is different. This variable always appears on the right-hand side of the equations in all five (sub)models of the CFSM-I. It means that, in the CFSM-I, there is no equation for PS^{MWrw}. Hence, except for the case of the (sub)model representing the MWrw market, where this variable is determined endogenously for the clearing of the market situation but exogenously for the non-clearing of the market situation, this variable is always exogenous.

Although tables that follow for the rest of the validation section present the values of the statistics for evaluating the forecast accuracy, how these values varied with respect to those of the equations validated in isolation (Table 5-11) is more important for the analysis of the validation results.

Validation of equations of each market under Non-MCC

Under Non-MCC, values shown in Table 5-12 of the mean of the predicted values (mean P), correlation coefficients (R) between the actual and predicted series, the inequality U_1 and the proportions U^m, U^s and U^c are, in general, similar to the values obtained when equations were validated in isolation. Hence, the conclusions about the performance of the CFSM-I's equations when validated in isolation, based on the cited statistics, still apply when they interact in the market they represent: a) there is a very good linear relation with positive slope between individual predictions P_t and the actual values A_t, characteristic of a good forecasting, b) they perform relatively well, c) there are no serious issues of systematic bias d) there exists a good replication of the variability (fluctuations) of A_t and e) the major share of the rmse is coming from unsystematic error.

However, when compared to naïve no-change extrapolation method of forecasting (benchmark method), two equations of the w, f, and z markets and three equations of the MWrw market perform equal or worse than this benchmark method, and for all seven equations, their values of the U_2 statistic worsened in comparison to the values obtained for the corresponding equations validated in isolation (see highlighted values in Table 5-12).

In the market of products of the wood industry w, equations for supply (S), consumption (C), exports X, export and import prices (PX and PM) result in forecasted values with a degree of accuracy ranging, on average, from 7% to 33% better than the benchmark method. On the other hand, equation for imports (M) has a $U_2 = 1$, i.e., results in forecasted values "equal" to those from the benchmark and the consumption price (PC) equation ($U_2 = 1.3$) leads to forecasted values with 30% less accuracy than the benchmark method.

For the market of products of the furniture industry f, equations for S, C, M, PC, and PM produce, on average, 10% to 56% more accurate values of forecasting for these endogenous variables than the naïve method. Predicted values obtained with equations for PX and X ($U_2 = 1.08$ and 1.05, in

Table 5-12 Measure of performance of Individual Behavioral Equations of the CFSM-I - Equations validated for each CFSM's Market in isolation, under Non-MCC

Market	Eq Number	Variable	R	U_1	U_2	U^m	U^s	U^c	Mean A	Mean P
Manufactured wood products of the wood industry, w	10	S_t^w	0.984	0.47	0.90	0.00003	0.00092	0.99905	2 501.72	2 500.74
	13	C_t^w	0.991	0.44	0.93	0.01747	0.10750	0.87503	2 346.51	2 371.32
	16	X_t^w	0.896	0.55	0.87	0.00005	0.07459	0.92536	46.69	46.58
	19	M_t^w	0.982	0.45	1.00	0.00023	0.20824	0.79153	184.84	185.63
	22	PC_t^w	0.992	0.68	1.30	0.01510	0.03428	0.95062	0.3812	0.3865
	25	PX_t^w	0.993	0.35	0.67	0.00140	0.00736	0.99123	0.5609	0.5591
	28	PM_t^w	0.988	0.46	0.81	0.00033	0.00407	0.99561	0.5076	0.5085
		PS_t^w								
Manufactured wood products of the furniture industry, f	11	S_t^f	0.996	0.36	0.61	0.00157	0.00001	0.99842	3 025.76	3 018.54
	14	C_t^f	0.997	0.31	0.62	0.00431	0.01892	0.97677	3 115.46	3 105.04
	17	X_t^f	0.854	0.53	1.08	0.00217	0.00457	0.99325	176.20	179.79
	20	M_t^f	0.975	0.42	0.90	0.00874	0.02130	0.96996	230.13	235.10
	23	PC_t^f	0.998	0.39	0.80	0.25252	0.11410	0.63339	0.4558	0.4423
	26	PX_t^f	0.977	0.74	1.05	0.02519	0.00176	0.97305	0.3863	0.3961
	29	PM_t^f	0.998	0.22	0.44	0.00016	0.00394	0.99589	0.4615	0.4611
		PS_t^f								
Manufactured wood products of the pulp and paper industry, z	12	S_t^z	0.996	0.36	0.73	0.00057	0.06459	0.93483	6 582.48	6 590.12
	15	C_t^z	0.994	0.39	0.83	0.01242	0.05631	0.93127	7 616.72	7 662.34
	18	X_t^z	0.972	0.52	1.16	0.01378	0.03842	0.94781	627.19	611.02
	21	M_t^z	0.802	0.47	3.12	0.00099	0.11524	0.88377	1 672.36	1 690.97
	24	PC_t^z	0.997	0.44	0.79	0.07041	0.10742	0.82217	0.4289	0.4371
	27	PX_t^z	0.998	0.19	0.37	0.00156	0.00692	0.99152	0.4314	0.4323
	30	PM_t^z	0.995	0.31	0.58	0.00000	0.03755	0.96244	0.3908	0.3908
		PS_t^z								
Unprocessed wood for the manufactured wood products industry & for final use other than firewood, MWrw	41	S_t^{MWfprw}	0.981	0.45	0.94	0.00031	0.12832	0.87137	286.71	285.78
	42	S_t^{MWnfrw}	0.967	0.52	0.95	0.00004	0.04702	0.95294	413.53	413.83
	48	C_t^{MWrw}	0.992	0.77	1.48	0.50126	0.23403	0.26471	671.99	603.56
	50	X_t^{MWrw}	0.894	0.60	0.86	0.02015	0.13983	0.84003	11.90	12.92
	52	M_t^{MWrw}	0.574	0.60	0.90	0.02036	0.22477	0.75486	1.83	1.42
	54	PC_t^{MWrw}	0.990	0.71	1.35	0.15222	0.05291	0.79487	0.4056	0.4255
	56	PX_t^{MWrw}	0.963	0.92	1.29	0.14380	0.19360	0.66260	0.2753	0.3135
	58	PM_t^{MWrw}	0.716	0.70	0.81	0.00008	0.15440	0.84553	0.2991	0.3009
		PS_t^{MWrw}								
Unprocessed wood for firewood, FWrw	43	S_t^{FWnfrw}	0.986	0.42	0.84	0.00089	0.01065	0.98846	485.16	483.95
	49	C_t^{FWrw}	0.961	0.65	1.56	0.00386	0.16472	0.83143	494.09	489.04
	55	PC_t^{FWrw}	0.997	0.41	0.81	0.05623	0.00036	0.94341	0.3541	0.3603
		PS_t^{FWrw}								

In yellow, statistics that worsened importantly with respect to those found when equations were validated in isolation

that order) are 5% and 8% less accurate than those obtained with the same benchmark method.

Regarding the market of products of the pulp & paper industry z, equations for S, C, PC, PX, PM, produce forecasting values that are 27% to 63% more accurate than the naïve method, in average. Predicted values obtained from equations for X and M (U_2 = 1.16 and 3.12, correspondingly) are 16% and 212% less accurate than those derived from the naïve method, on average.

For the unprocessed wood for the manufactured wood products industry & for final use other than firewood MWrw, the equations of S, X, M, and PM result, on average, in values of the 1977-2015 series forecasted that are 5% to 19% better than those obtained from the naïve method. Equations of PX, PC and C (U_2 = 1.29, 1.35, and 1.48, respectively) generate forecast series between 29% and 48% less accurate, on average. Finally, the equations for S, C and PC representing the market of the unprocessed wood for firewood FWrw, produce quite similar forecasting to those presented in the section for equations validated in isolation.

The decline in the performance of the nine equations for the markets of w, f, z and MWrw (measured by U_2) with respect to their performance as isolated equations is ascribable to a) poor adjustments of the equations for the first years of the series 1977-2015, b) the influence of the smallest predicted values for the prices (which are deflators) at the beginning of the series, especially when those prices are in the denominator of relative prices c) some outliers in the series of actual data and d) the interactions of the equations in the context of the isolated markets when an equation can be affected by a), b) and c) at the same time.

For example, the forecast values for the first years of the 1977-2015 series of S^w are greater in the validation of isolated markets than those from validation in isolated equations. As the PC^w equation depends negatively on the S^w, larger values of S^w causes values of the PC^w (already quite small) in the former validation case to be smaller than in the latter. That means that forecasted values are farther from their actual values for isolated markets, resulting in greater predicted error for those years, which in turn affects the rms predicted error with the obvious consequences in the computation of U_2. Recall that PC^w is on the right-hand side of the equations of M^w. As a result, all the effects of larger values of S^w and smaller values of PC^w are then reflected in the M^w, which means that U_2 worsens with respect to the one obtained when validating the M^w equation in isolation.

Finally, special consideration is needed for the equation of C^{MWrw}, given that not only it performs worse (U_2 = 1.48) than when in isolation (U_2 = 0.71), but it now presents serious issues of systematic bias (U^m = 0.501), which was absent before (U^m = 0.029). As already discussed, this type of bias is worrisome and a modeler should try to correct it with some strategy, e.g. trying another equation. However, no action to correct this equation (or any other equations performing worse than the naïve method of forecasting) was done in this case, since the objective of building the CFSM-I is the MCC, and not the non-clearing case. Some of the issues that arose during the equation validation in the case where MCC does not hold for each market pertaining to the CFSM-I are presented in the graphs of the Appendix 5-2.

Validation of equations of each market under MCC

The performance measures of the equations pertaining to each of the five markets of the CFSM-I under the MCC are shown Table 5-13. In this table, the statistics for each market refer only to the period for which the algorithms of MS Excel Solver® (see section 5.6), found solutions for the MCC (e.g., 1984-2015 for the products of the pulp & paper industry z)[51]. For the same periods, Table 5-13 also includes the same statistics of forecast accuracy for equations validated in isolation, for comparison.

In general, in both situations, equations and markets in isolation, equations perform well (see U_1 and U_2). The forecasted values (Pt) of the endogenous variables obtained from these equations can be deemed a good forecasting, given that a very good linear relation with positive slope between individual predictions P_t and the actual values A_t exists, means of P and A are relatively close, no serious issues of systematic bias is present, the replication of variability of the actual series is good, and the origin of the rmse is from unsystematic error.

[51] For a particular year, to find a MCC solution for an individual market (e.g. the z market), MS Excel Solver® searches for the Price of Supply (PS) that makes the objective function Supply (S) – Demand (D) = 0, subject to the restriction that PS and all values of the endogenous variables for which the CFSM-I has a behavioral equation, i.e., S, Consumption (C), Exports (X), Imports (M) and their corresponding prices PC, PX and PM are positive.

Table 5-13 Measure of performance of Individual Behavioral Equations of the CFSM Phase I - Equations validated for each CFSM's Market in isolation, under MCC

Market	Period for which Solver® found a solution for MCC	Eq Number	Variable	Markets in isolation								Equations in Isolation							
				R	U_1	U_2	U^m	U^s	U^c	Mean A	Mean P	R	U_1	U_2	U^m	U^s	U^c	Mean A	Mean P
Manufactured wood products of the wood industry, w	1997-2015	10	S_t^w	0.840	0.59	1.31	0.19004	0.08771	0.72225	3 429.67	3 289.21	0.866	0.48	0.94	0.00225	0.00455	0.99320	3 429.67	3 440.68
		13	C_t^w	0.950	0.46	0.99	0.12803	0.05714	0.81484	3 477.24	3 563.34	0.949	0.45	0.99	0.12753	0.04311	0.82936	3 477.24	3 562.77
		16	X_t^w	0.785	0.54	0.85	0.00001	0.33323	0.66676	73.99	74.05	0.788	0.54	0.85	0.00000	0.32832	0.67168	73.99	73.96
		19	M_t^w	0.985	0.38	0.71	0.01196	0.24079	0.74726	353.81	348.18	0.986	0.39	0.76	0.07731	0.34765	0.57504	353.81	338.34
		22	PC_t^w	0.996	0.25	0.49	0.00425	0.16590	0.82985	0.6886	0.6873	0.995	0.26	0.50	0.01206	0.09702	0.89092	0.6886	0.6863
		25	PX_t^w	0.945	0.28	0.58	0.00609	0.08574	0.90816	0.9531	0.9491	0.945	0.28	0.58	0.00609	0.08574	0.90816	0.9531	0.9491
		28	PM_t^w	0.913	0.33	0.63	0.00023	0.00072	0.99905	0.8032	0.8025	0.914	0.33	0.63	0.00031	0.00027	0.99942	0.8032	0.8024
			PS_t^w	0.949	0.88	3.72	0.31005	0.38975	0.30021	0.6539	0.5669								
Manufactured wood products of the furniture industry, f	1977-2015	11	S_t^f	0.994	0.37	0.75	0.01327	0.01853	0.96820	3 025.76	3 051.46	0.996	0.36	0.61	0.00157	0.00001	0.99842	3 025.76	3 018.54
		14	C_t^f	0.997	0.30	0.62	0.00377	0.02081	0.97542	3 115.46	3 105.70	0.997	0.30	0.62	0.00417	0.02120	0.97464	3 115.46	3 105.23
		17	X_t^f	0.858	0.46	1.09	0.00060	0.00171	0.99769	176.20	178.12	0.906	0.45	0.87	0.00226	0.11510	0.88264	176.20	179.14
		20	M_t^f	0.981	0.40	0.80	0.00610	0.01819	0.97571	230.13	233.80	0.985	0.35	0.71	0.01543	0.03985	0.94472	230.13	235.35
		23	PC_t^f	0.998	0.27	0.61	0.00059	0.00155	0.99786	0.4558	0.4553	0.999	0.27	0.60	0.00049	0.00292	0.99659	0.4558	0.4554
		26	PX_t^f	0.986	0.50	0.81	0.00053	0.01407	0.98540	0.3863	0.3874	0.986	0.50	0.81	0.00038	0.01302	0.98660	0.3863	0.3872
		29	PM_t^f	0.999	0.17	0.35	0.00000	0.00160	0.99840	0.4615	0.4614	0.999	0.17	0.35	-	0.00163	0.99837	0.4615	0.4615
			PS_t^f	0.993	0.53	1.40	0.02177	0.02405	0.95418	0.4513	0.4580								
Manufactured wood products of the pulp and paper industry, z	1984-2015	12	S_t^z	0.993	0.40	0.85	0.08188	0.08951	0.82861	7 463.00	7 579.02	0.994	0.36	0.72	0.00073	0.05718	0.94209	7 463.00	7 453.71
		15	C_t^z	0.991	0.38	0.81	0.01903	0.02722	0.95375	8 659.36	8 719.24	0.991	0.40	0.85	0.01560	0.03133	0.95307	8 659.36	8 716.00
		18	X_t^z	0.976	0.52	0.998	0.01320	0.08473	0.90207	739.94	725.01	0.976	0.52	0.998	0.03775	0.04580	0.91644	739.94	714.70
		21	M_t^z	0.979	0.41	0.85	0.00001	0.12907	0.87092	1 865.67	1 865.23	0.988	0.33	0.58	0.00129	0.00000	0.99871	1 865.67	1 861.59
		24	PC_t^z	0.997	0.30	0.55	0.00234	0.00004	0.99762	0.5190	0.5201	0.997	0.30	0.56	0.00315	0.00136	0.99549	0.5190	0.5203
		27	PX_t^z	0.997	0.18	0.34	0.01732	0.07942	0.90326	0.5229	0.5259	0.997	0.18	0.34	0.01732	0.07942	0.90326	0.5229	0.5259
		30	PM_t^z	0.994	0.26	0.52	0.00001	0.04062	0.95936	0.4738	0.4737	0.994	0.26	0.52	0.00005	0.04576	0.95420	0.4738	0.4740
			PS_t^z	0.990	0.46	1.16	0.12264	0.00544	0.87192	0.5348	0.5518								
Unprocessed wood for the manufactured wood products industry & for final use other than firewood, MWrw	1983-2015	41	S_t^{MWfprw}	0.981	0.45	0.89	0.10195	0.14236	0.75569	337.29	320.24	0.976	0.45	0.93	0.00442	0.11553	0.88006	337.29	333.55
		42	S_t^{MWnfrw}	0.975	0.46	0.82	0.04289	0.05210	0.90501	439.01	429.92	0.965	0.52	0.94	0.00459	0.08741	0.90800	439.01	442.45
		48	C_t^{MWrw}	0.995	0.36	0.70	0.04292	0.29419	0.66289	747.57	737.30	0.994	0.36	0.71	0.03471	0.30611	0.65918	747.57	738.16
		50	X_t^{MWrw}	0.884	0.61	0.87	0.01001	0.15137	0.83862	13.97	14.74	0.884	0.61	0.87	0.00993	0.14908	0.84098	13.97	14.74
		52	M_t^{MWrw}	0.590	0.59	0.86	0.00534	0.25743	0.73723	2.10	1.88	0.582	0.58	0.87	0.00179	0.26363	0.73459	2.10	1.97
		54	PC_t^{MWrw}	0.995	0.37	0.75	0.02491	0.00965	0.96544	0.4760	0.4809	0.995	0.36	0.73	0.00948	0.02122	0.96930	0.4760	0.4790
		56	PX_t^{MWrw}	0.963	0.49	0.88	0.00017	0.02368	0.97615	0.3252	0.3262	0.963	0.49	0.88	0.00017	0.02368	0.97615	0.3252	0.3262
		58	PM_t^{MWrw}	0.666	0.64	0.79	0.00015	0.17940	0.82045	0.3513	0.3485	0.668	0.64	0.79	0.00019	0.18068	0.81914	0.3513	0.3482
			PS_t^{MWrw}	0.988	0.54	1.33	0.24242	0.01453	0.74305	0.4663	0.4395								
Unprocessed wood for firewood, FWrw	1983-2005	43	S_t^{FWnfrw}	0.947	0.55	1.33	0.33769	0.00002	0.66229	634.95	681.67	0.970	0.42	0.82	0.00147	0.11003	0.88850	634.95	636.85
		49	C_t^{FWrw}	0.934	0.55	1.26	0.15386	0.02086	0.82528	649.34	681.67	0.935	0.55	1.26	0.11867	0.00066	0.88067	649.34	677.62
		55	PC_t^{FWrw}	0.995	0.27	0.55	0.00387	0.05416	0.94197	0.2372	0.2361	0.995	0.26	0.54	0.00077	0.02561	0.97362	0.2372	0.2377
			PS_t^{FWrw}	0.541	1.18	316.01	0.53361	0.45549	0.01090	0.2360	7.5769								

In yellow, statistics that worsened importantly with respect to those found when equations were validated in isolation

While some equations perform better or equal in the context of the market than in isolation, others perform worse. The cases of equations for S^w, X^f, and S^{FWrw}, whose U_2 statistic is > 1, and highlighted in Table 5-13, deserve extra attention. For the first two cases, U_2 worsened, indicating that the forecast accuracy of using this equation in markets of w and f is less if compared to that of using them in isolation (U_2 = 1,31 and 1,09 vs U2 = 0,94 and 0,87, respectively). In addition, under isolated market, these equations result in forecasted values of 31% and 7% worse than if the naïve method of forecasting were to be used, a non-desirable outcome. The case of S^{FWrw}, when U_2 and U^m went from 0.82 to 1.33 and 0.01 to 0.33, respectively, is more troublesome, as in the context of the market of FWrw, not only does the equation perform worse than the naïve method of forecasting, but it also shows some issues of systematic bias. Several trials were performed in order to find other equations that solve the issues mentioned, but none of the alternative equations tested improve the situations and, in many cases, other equations of each market worsened the measures of performance. Hence, the estimated behavioral equations presented in tables 5-5 and 5-6 were kept.

Finally, it is important to draw attention to the forecast accuracy measures for PS under the MCC situation, initially for the w, f, z and FWrw markets. The value of R between individual predictions P_t and the actual values A_t is high for all these four markets (> 0.94). In this case, high R simply signals that, in average, PS series predicted by the partial equilibrium sub(model) to reach the MCC (PS^P), closely follows the slope and sign of the series of actual values (PS^A). In other words, PS^P and PS^A follow a very similar trajectory, independent of whether the values of the series are close or far from each other.

How close PS^P and PS^A are is signaled by U_1 and U_2, the bigger the value of these statistics the farther the distance between the two series, on average. Note in table 5-13 the U_1 and U_2 values for PS^z (0.46 and 1.16), PS^f (0.53 and 1.4), PS^{MWrw} (0.54 and 1.33) and PS^w (0.88 and 3.72). These values mean that, in reality, the markets modeled are far from the clearing condition, on average, during the period for which a solution was found by MS Excel Solver®. In other words, solver had to adjust (reduce or increase) the actual prices for all or some years of that period for finding the MCC. On average, the adjustments were bigger in the case of the market of w, lower for the market of f and MWrw, and much lower for the market of z. Then, in that order, the markets were farther and farther from clearing, on average, during the periods shown in the second column of Table 5-13. In the case of the market of FWrw, solver only found solutions for the MCC for 1983-2005 and adjusted the PS in such way that R=0,541, U_1=1.18 and U_2=361.01, which signals that this market is far from MCC and/or equations perform really bad for that condition of the simulation. The means of the actual and forecasted values shown in Table 5-13 support the analysis presented in this paragraph. A more clear picture can also be seen in the graphs of the PS^P and PS^A of each market under MCC in Appendix 5-2.

5.5.1.3 Forecast Accuracy of Individual Equations interacting as an aggregated market (all CFSM-I markets connected)

Validation under this title refers to validating the complete CFSM Phase I (CFSM-I) working as a unit, closer to how the aggregated market it models, the Wood Forest Products (WFP) market, works in real life. In this case, all (sub)models representing the five markets that make up the aggregated market WFP have their connecting variables (Sw, Sf, Sz and PCMwrw and PSMwrw) "active". This means that interactions are allowed between (sub)models, and as such, for any particular year, solutions are found in all (sub)models (w, f, z, MWrw and FWrw) and the aggregated model (WFP) simultaneously. To allow that, 12 summation identities and 7 market clearing identities are used in addition to the 32 behavioral estimated equations for the CFSM-I [52].

In this section, validation of the CFSM-I is presented for the Non-MCC and MCC cases. For the former, the clearing identity that equals supply to demand in the aggregated market of WFP is absent as well as the clearing identities for each of the five individual markets w, f, z, MWrw and Fwrw. In the latter, all 32 behavioral equations, the summation identities, and all clearing identities mentioned in the last paragraph work.

As the raw material for the products included in the Colombian market of unprocessed wood for firewood, FWrw, is in general quite different to that of the Colombian market of unprocessed wood

[52] CFSM-I's identities and final estimated behavioral equations are found in tables 3-2 and 3-4 (chapter 3), and tables 5-5 and 5-6 (chapter 5), respectively. In tables 3-4, four additional identities (Eq 3-44 to 3-47) are reported as part of the CFSM-I. These are used for estimating the variables named VH, VG, and VAST, and they are only used for the Colombian Forest Plantation Growth and Yield Simulator, explained in chapter 6. For more details on these identities and the results they produce see also chapter 3 and Appendix 4-3.

for the manufactured wood products & for final use other than firewood[53], and since the former is weakly linked to the other four markets modelled, the validation for the CFSM-I was also done without considering the FWrw market (i.e., "turning off" the partial equilibrium (sub)model for FWrw).

When the MCC does not hold, measures of performance of the CFSM-I (Table 5-14) are the same for both cases of validation, with and without the FWrw. Compared to the performance under isolated equations (Table 5-11), some equations deteriorated up to the point where their U_2 statistic signals that they perform equal or even worse than the naïve method of extrapolation (see the highlighted U_2 in Table 5-14). Nevertheless, other statistics such as R, mean of P, and the U_m and U_c indicate that the performance of those equations did not worsen by much. In general, it can be said that, in the absence of market-clearing, with and without the FWrw market, the equations of the CFSM-I perform relatively well, their predicted series of the endogenous variables track very well the actual values, and no significant issues of systematic bias and replicability of the variation of the actual series is present.

For the MCC case, the algorithms of MS Excel Solver® found solutions only when the CFSM-I was executed without considering the FWrw market. Also, these solutions covered just the period 1997-2015, as for the years 1977-1996 the solver could not find any viable solutions for the MCC of the aggregated market that is modeled, i.e., the WFP (without FWrw) which means that this market was far from clearing. Measures of forecast accuracy resulting from using the solutions found for the period 1997-2015, the forecasted values from each individual equations for the same period, and the 1997-2015 actual values of all endogenous variables of the CFSM-I, are presented in Table 5-15. Notice that, for the MCC, the CFSM-I without the FWrw (sub)model, predicts 33 endogenous variables, 29 using behavioral equations and 4 (the prices of supply PS) using the clearing identities.

In general terms, the 29 behavioral equations of the CFSM-I, without including the FWrw market, perform well. The model is able to predict 26 out of 29 endogenous variables without major issues, i.e., close means of individual predictions P_t and actual values A_t, good linear relation with positive

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[53] See Table 3-1 for more details about the difference between the FWrw and MWrw in Colombia.

slope between P_t and A_t, no systematic bias, good replicability of the variation of A_t, and major share of the rmse coming from unsystematic error.

For the rest of the endogenous variables estimated with behavioral aquations, some issues (highlighted in Table 5-15) are present. For S^w, $U_2 = 1.31$ indicates that its corresponding equation

Table 5-14 Measure of performance of Individual Behavioral Equations of the CFSM Phase I Equations validated for all CFSM markets connected, under No MCC

Aggregated Market	Aggregated (sub)Market	Market	Eq Number	Variable	R	U_1	U_2	U^m	U^s	U^c	Mean A	Mean P
Wood forest products, WFP	Manufactured wood (forest) products, MW	Manufactured wood products of the wood industry, w	10	S_t^w	0.984	0.47	0.91	0.00002	0.00094	0.99904	2 501.72	2 500.80
			13	C_t^w	0.991	0.44	0.93	0.01747	0.10752	0.87501	2 346.51	2 371.32
			16	X_t^w	0.896	0.55	0.87	0.00005	0.07459	0.92536	46.69	46.58
			19	M_t^w	0.982	0.45	1.00	0.00023	0.20826	0.79151	184.84	185.63
			22	PC_t^w	0.992	0.68	1.30	0.01512	0.03427	0.95061	0.3812	0.3865
			25	PX_t^w	0.993	0.35	0.67	0.00140	0.00736	0.99123	0.5609	0.5591
			28	PM_t^w	0.988	0.46	0.81	0.00033	0.00407	0.99561	0.5076	0.5085
				PS_t^w							0.3593	
		Manufactured wood products of the furniture industry, f	11	S_t^f	0.996	0.36	0.61	0.01688	0.00159	0.98153	3 025.76	3 002.11
			14	C_t^f	0.997	0.31	0.62	0.00434	0.01896	0.97670	3 115.46	3 105.01
			17	X_t^f	0.854	0.53	1.08	0.00217	0.00457	0.99325	176.20	179.79
			20	M_t^f	0.975	0.42	0.90	0.00876	0.02132	0.96992	230.13	235.11
			23	PC_t^f	0.998	0.38	0.79	0.23202	0.09690	0.67108	0.4558	0.4431
			26	PX_t^f	0.977	0.74	1.05	0.02519	0.00176	0.97305	0.3863	0.3961
			29	PM_t^f	0.998	0.22	0.44	0.00016	0.00394	0.99589	0.4615	0.4611
				PS_t^f							0.4513	
		Manufactured wood products of the pulp and paper industry, z	12	S_t^z	0.995	0.37	0.77	0.00000	0.03877	0.96123	6 582.48	6 582.73
			15	C_t^z	0.994	0.39	0.83	0.01255	0.05703	0.93043	7 616.72	7 662.72
			18	X_t^z	0.972	0.52	1.16	0.01378	0.03842	0.94781	627.19	611.02
			21	M_t^z	0.802	0.47	3.11	0.00100	0.11471	0.88429	1 672.36	1 691.04
			24	PC_t^z	0.997	0.44	0.79	0.07286	0.10540	0.82174	0.4289	0.4373
			27	PX_t^z	0.998	0.19	0.37	0.00156	0.00692	0.99152	0.4314	0.4323
			30	PM_t^z	0.995	0.31	0.58	0.00000	0.03774	0.96226	0.3908	0.3908
				PS_t^z							0.4418	
	Unprocessed wood, UW (also known as raw wood, rw)	Unprocessed wood for the manufactured wood products industry & for final use other than firewood, MWrw	41	S_t^{MWfprw}	0.981	0.45	0.94	0.00031	0.12832	0.87137	286.71	285.78
			42	S_t^{MWnfrw}	0.967	0.52	0.95	0.00004	0.04702	0.95294	413.53	413.83
			48	C_t^{MWrw}	0.992	0.40	0.88	0.02137	0.15424	0.82438	671.99	663.60
			50	X_t^{MWrw}	0.894	0.60	0.86	0.02015	0.13983	0.84003	11.90	12.92
			52	M_t^{MWrw}	0.586	0.58	0.88	0.00196	0.22940	0.76864	1.83	1.71
			54	PC_t^{MWrw}	0.990	0.71	1.35	0.15222	0.05291	0.79487	0.4056	0.4255
			56	PX_t^{MWrw}	0.963	0.92	1.29	0.14380	0.19360	0.66260	0.2753	0.3135
			58	PM_t^{MWrw}	0.716	0.70	0.81	0.00008	0.15440	0.84553	0.2991	0.3009
				PS_t^{MWrw}							0.3972	
		Unprocessed wood for firewood, FWrw	43	S_t^{FWnfrw}	0.986	0.42	0.84	0.00089	0.01065	0.98846	485.16	483.95
			49	C_t^{FWrw}	0.961	0.65	1.56	0.00386	0.16472	0.83143	494.09	489.04
			55	PC_t^{FWrw}	0.997	0.41	0.81	0.05623	0.00036	0.94341	0.3541	0.3603
				PS_t^{FWrw}							0.3537	

In yellow, statistics that worsened importantly with respect to those found when equations were validated in isolation

Table 5-15 Measure of performance of Individual Behavioral Equations of the CFSM Phase I - Equations validated when all CFSM-I markets are connected, under MCC

Aggregated Market and Period for which Solver® found a solution for MCC	Aggregated (sub)Market	Market	Eq Number	Variable	All markets connected (no FWrw included)								Equations in Isolation							
					R	U_1	U_2	U^m	U^s	U^c	Mean A	Mean P	R	U_1	U_2	U^m	U^s	U^c	Mean A	Mean P
Wood forest products, WFP (1997-2015) without FWrw	Manufactured wood (forest) products, MW	Manufactured wood products of the wood industry, w	10	S_t^w	0.840	0.60	1.31	0.19004	0.08771	0.72225	3 429.67	3 289.21	0.866	0.48	0.94	0.00225	0.00455	0.99320	3 429.67	3 440.68
			13	C_t^w	0.950	0.46	0.99	0.12803	0.05714	0.81484	3 477.24	3 563.34	0.949	0.45	0.99	0.12753	0.04311	0.82936	3 477.24	3 562.77
			16	X_t^w	0.785	0.54	0.85	0.00001	0.33323	0.66676	73.99	74.05	0.788	0.54	0.85	0.00000	0.32832	0.67168	73.99	73.96
			19	M_t^w	0.985	0.38	0.71	0.01196	0.24079	0.74726	353.81	348.18	0.986	0.39	0.76	0.07731	0.34765	0.57504	353.81	338.34
			22	PC_t^w	0.996	0.25	0.49	0.00425	0.16590	0.82985	0.6886	0.6873	0.995	0.26	0.50	0.01206	0.09702	0.89092	0.6886	0.6863
			25	PX_t^w	0.945	0.28	0.58	0.00609	0.08574	0.90816	0.9531	0.9491	0.945	0.28	0.58	0.00609	0.08574	0.90816	0.9531	0.9491
			28	PM_t^w	0.913	0.33	0.63	0.00023	0.00072	0.99905	0.8032	0.8025	0.914	0.33	0.63	0.00031	0.00027	0.99942	0.8032	0.8024
				PS_t^w	0.948	0.88	3.69	0.30872	0.38454	0.30674	0.6539	0.5677								
		Manufactured wood products of the furniture industry, f	11	S_t^f	0.981	0.39	0.66	0.11062	0.05135	0.83803	4 878.70	4 965.17	0.981	0.38	0.61	0.00334	0.00788	0.98878	4 878.70	4 864.72
			14	C_t^f	0.992	0.28	0.57	0.04268	0.00272	0.95460	5 057.35	5 093.61	0.993	0.27	0.56	0.04758	0.00417	0.94825	5 057.35	5 094.92
			17	X_t^f	0.907	0.53	0.91	0.00028	0.38237	0.61735	256.33	257.28	0.933	0.49	0.80	0.00069	0.41735	0.58196	256.33	257.64
			20	M_t^f	0.976	0.40	0.78	0.03698	0.09647	0.86655	374.02	385.72	0.983	0.34	0.68	0.01612	0.15089	0.83298	374.02	380.75
			23	PC_t^f	0.982	0.30	0.76	0.00330	0.00370	0.99300	0.8064	0.8080	0.983	0.31	0.74	0.00538	0.00511	0.98951	0.8064	0.8084
			26	PX_t^f	0.839	0.51	0.82	0.00198	0.10198	0.89604	0.6429	0.6456	0.839	0.52	0.82	0.00198	0.10198	0.89604	0.6429	0.6456
			29	PM_t^f	0.989	0.17	0.34	0.00341	0.00032	0.99627	0.8246	0.8230	0.989	0.17	0.34	0.00362	0.00031	0.99607	0.8246	0.8230
				PS_t^f	0.960	0.51	1.37	0.21741	0.03623	0.74636	0.7980	0.8200								
		Manufactured wood products of the pulp and paper industry, z	12	S_t^z	0.987	0.38	0.76	0.01939	0.14651	0.83411	9 423.14	9 482.43	0.989	0.35	0.67	0.04265	0.06995	0.88740	9 423.14	9 345.23
			15	C_t^z	0.984	0.38	0.80	0.11402	0.06096	0.82502	10 650.14	10 811.60	0.982	0.41	0.86	0.10857	0.06193	0.82950	10 650.14	10 818.73
			18	X_t^z	0.959	0.52	0.98	0.14648	0.00000	0.85352	1 093.46	1 034.31	0.958	0.53	0.99	0.13678	0.00002	0.86320	1 093.46	1 035.77
			21	M_t^z	0.958	0.42	0.77	0.07176	0.01356	0.91469	2 318.61	2 363.48	0.974	0.35	0.59	0.00009	0.01239	0.98752	2 318.61	2 317.41
			24	PC_t^z	0.982	0.32	0.57	0.00358	0.04727	0.94916	0.7604	0.7621	0.982	0.34	0.58	0.00374	0.08630	0.90995	0.7604	0.7622
			27	PX_t^z	0.987	0.14	0.27	0.01492	0.06974	0.91534	0.7494	0.7467	0.987	0.14	0.27	0.01492	0.06974	0.91534	0.7494	0.7467
			30	PM_t^z	0.960	0.26	0.52	0.00576	0.09726	0.89698	0.7019	0.6987	0.961	0.26	0.51	0.00732	0.07061	0.92208	0.7019	0.6984
				PS_t^z	0.942	0.51	1.17	0.17858	0.07930	0.74212	0.7779	0.8012								
	Unprocessed wood, UW (also known as raw wood, rw) without FWrw	Unprocessed wood for the manufactured wood products industry & for final use other than firewood, MWrw	41	S_t^{MWfprw}	0.984	0.41	0.79	0.06663	0.36530	0.56807	456.05	440.78	0.975	0.45	0.93	0.00301	0.37233	0.62466	456.05	459.88
			42	S_t^{MWnfrw}	0.901	0.51	0.97	0.15701	0.00908	0.83390	577.26	552.37	0.881	0.51	0.93	0.01310	0.03644	0.95045	577.26	570.36
			48	C_t^{MWrw}	0.985	0.39	0.80	0.23665	0.07601	0.68734	1 004.48	971.19	0.989	0.37	0.74	0.10896	0.32940	0.56164	1 004.48	983.55
			50	X_t^{MWrw}	0.807	0.61	0.86	0.00137	0.22646	0.77216	22.75	23.11	0.808	0.60	0.85	0.00126	0.22058	0.77816	22.75	23.10
			52	M_t^{MWrw}	0.342	0.57	0.86	0.02252	0.12262	0.85485	1.39	1.15	0.416	0.58	0.79	0.00101	0.26082	0.73817	1.39	1.43
			54	PC_t^{MWrw}	0.973	0.40	0.82	0.02989	0.20826	0.76184	0.7042	0.7110	0.974	0.39	0.79	0.00540	0.19815	0.79644	0.7042	0.7070
			56	PX_t^{MWrw}	0.913	0.49	0.87	0.00331	0.24443	0.75226	0.5239	0.5283	0.913	0.50	0.87	0.00331	0.24443	0.75226	0.5239	0.5283
			58	PM_t^{MWrw}	0.261	0.64	0.79	0.00021	0.44497	0.55482	0.5124	0.5080	0.269	0.64	0.79	0.00025	0.44744	0.55232	0.5124	0.5077
				PS_t^{MWrw}	0.960	0.69	1.46	0.29922	0.19046	0.51033	0.6936	0.6550								

In yellow, statistics that worsened importantly with respect to those found when equations were validated in isolation

perform, on average, 31% worse than if the forecast was performed with the naïve method of extrapolation (the benchmark). Compared to the performance of the isolated equation, in the context of the MCC this equation worsens, resulting not only in doing worse than the benchmark but exhibiting some systematic bias ($U^m = 0.19$), both inexistent problems when used isolated. The explanation for this negative change can be attributed to the PS^w values forecasted by the solver to find the MCC in the market of w, which are lower than the actual values, that reduce the forecasted S^w and widen the rms prediction error of this endogenous variable.

For PM^{Mwrw} and M^{Mwrw} issues on replicability of the variation of the actual data series for the first, and good tracking of A_t for both emerged. These problems were already present for the behavioral equations when validated in isolation. The main culprit for the lack of tracking of the Pt in relation to that of the A_t are the outliers of the actual data for PM and the intermittent data of M, which did not allow for an estimation of equations with good statistical properties for these two variables.

Finally, regarding the endogenous variables PS^w, PS^f, PS^z and PS^{MWrw} it is worth noting that values of forecast accuracy statistics shown in Table 5-15 are quite similar to those of Table 5-13. Given this similarity, there is little to add to what was already discussed under the *Validation of equations of each market under MCC*, section 5.1.5.2.

5.5.2 *Ex post* forecast

The ability of the CFSM-I to predict the endogenous variables for the 2016-2018 period out-of-sample (i.e., to produce the *ex post* forecast) was tested. For this, the model was simulated for the option of all the markets connected, without including the FWrw (sub)model, under both the Non-MCC and MCC cases, using the values of the exogenous variables from 1997 to 2018. Using the results of these simulations, measures of forecast accuracy were computed and then compared to those of forecasting the endogenous variables with equations in isolation. Measures of forecast accuracy for equations in isolation and the complete CFSM-I without FWrw for the MCC of the period 1997-2018 are quite similar to those of 1997- 2018 presented in table 5-15. Also, measures of forecast accuracy for the Non-MCC signal that equations perform well. Hence, it can be concluded that the model equations in isolation give a good forecasting of the 29 endogenous variables they represent and that the CFSM-I, without FWrw, can consistently predict 29 and 33 endogenous key variables of the Colombian wood forest product market under the non-clearing and clearing cases of this market, respectively. In the interest of saving space, tables showing the measures of forecast accuracy for the *ex post* forecast have been moved to Appendix 5-2.

5.5.3 Responses to stimuli and Overall sensitivity of the CFSM-I

Following Pindick & Rubinfield (1998), the CFSM-I was subject to both larger changes in exogenous variables or policy parameters (stimuli), and changes in the year the simulation starts. Larger changes in the exogenous variables VAST, K, and HCS were made to investigate whether or not the CFSM-I responded. The model responds to stimuli according to the elasticities presented in section 5.4.1, unfortunately no other relationship of between VAST, K, and HCS and the rest of the variables of the CFSM-I have been estimated for comparison. Measures of forecast accuracy for the 1982-2018 simulation and the 1977-2018 simulation were not significantly different for individual equations interacting in the context of Isolated Market. Also, for equations interacting in the context of the CFSM-I as a unit (i.e., as the WFP market, without FWrw) under the MCC, the measures of forecast accuracy for the 2002-2018 simulation were not importantly different from those of the 1997-2018 simulation. More information on testing under this subsection can be found in Appendix 5-2.

5.6 Software application for the CFSM-I

During this research, a software application with the final purpose of solving the CFSM was built in Excel using Visual Basic for Applications. Named *CFSM-I App*, this application has the following capabilities:

a) To keep and display all data used for the sectoral analysis of the Colombian forest sector (1970-2018 consolidated time series), estimating the CFSM-I (1975-2015 consolidated time series), and using the CFSM-I for forecasting and scenario analysis (2019-2023 forecasted time series and 2024-2100 scenario time series).
b) To validate each estimated behavioral equation of the CFSM: (1) in isolation, (2) when MCC doesn't hold (market doesn't clear) and MCC of each of the isolated five markets

considered in the CFSM, i.e., w, f, z, MWrw, FWrw, and (3) when No MCC and MCC cases of all five markets connected

c) To solve the model, i.e find the values of prices and quantities under the MCC for: (1) the w, f, z, MWrw and FWrw markets in isolation, (2) the Unprocessed Wood Market UWM (sum of MWrw and FWrw) and the manufactured WM (sum of w, f, z) in isolation, and (3) for w, f, z, MWrw and FWrw markets when all them are connected (4) for w, f, z and MWrw markets when all four markets are connected

The *CFSM-I App* can solve the model for a "current" year as follows:

a. Recursively: using the values of the exogenous variables of the current year and the values of lagged variables found by the solver algorithm for the preceding years whether or not the solver found a solution for the MCC case in those years
b. Non-recursively (Only for validation): using the values of the exogenous variables of the current year and the values of lagged variables coming from one of the following options: (1) historical data values, (2) data values from validation of each equation considered in isolation, (3) data values from validation of each equation considering isolated markets, (4) data values from validation of each equation considering all markets connected at iteration 0

To solve the model *CFSM-I App* can use the primal Simplex[54] and the Generalized Reduced Gradient (GRG Non-linear)[55] methods which are already part of the add-on modules in Microsoft Excel Solver®.

The *CFSM-I App* reports the solution combined (for years of Non-MCC, the data values from which the solver starts are reported and for years of MCC, the solution values of the solver are reported) or not combined (solution values of the solver are reported in every year independently whether or not it found solutions for MCC).

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[54] Based on the Simplex Method "originally developed by Dantzig in 1948" (https://www.solver.com/linear-quadratic-programming accessed on August 19, 2022)

[55] As implemented in an enhanced version of Lasdon and Waren's GRG2 code (https://www.solver.com/smooth-nonlinear-technology accessed on August 19, 2022)

In solving the CFSM-I, all adjustments for forcing the market clearing (MC) are made to the price of supply (PS_t) in each market. An additional feature of "turning off" the equations of prices of consumption (PC_t), prices of export (PX_t) and prices of imports (PM_t) and adjusting those four prices in each market to force the MC has also been programmed. A feature determining the point (data values) where the iterations for forcing the MC start is also included.

Finally, three last features complete the *CFSM-I App*:

a) Data export capacity for transferring the data to a simpler software application, also built in Excel®, to calculate and report several measures of performance of the 32 equations, 5 markets and the whole CFSM-I
b) Dealing with negative data resulting from executing capabilities of Validation and Solving. When negative data values arise from using these capabilities in a particular year, the app can (1) change the negative data to the historical data, (2) change it to zero, (3) leave it as is. Independent of the restrictions of positive values for all endogenous variables, given the several options to solve and validate the model, some negative values might arise in a particular year which can affect the consecutive computations of the years ahead.
c) Exporting the data to a fully graphical output very useful in conducting several analyses.

The *CFSM-I App* and its user's manual can be found in Appendix 5-3.

This chapter successfully resolves the first specific objective of this research, the development of the CFSM. The next two chapters that follow, 6 and 7, are dedicated to the results of accomplishing the second, third, and fourth research specific objectives.

Chapter 6
Colombian Forest Plantation Growth and Yield Simulator (SCRPFC) and Estimations of volume of wood in forest plantations (VAS) for 2015-2047

This chapter presents the results of the work done for achieving the second and fourth specific objectives of the research. Both objectives, evaluating the goal of the Forest Development National Plan (FDNP) of the expansion of commercial forest plantation for wood production area by 1.5 million hectares- Mha, and comparing these results to to five additional scenarios of alternative forest plantation area: 0.3 Mha, 0.45 Mha, 0.765 Mha and 2.0 Mha under sustainable rotation, and 0.3 Mha harvested without replanting, are achieved partially in chapter 6. These objectives are completed in chapter 7, which uses the results presented in the current chapter as inputs.

Chapter 6 corresponds to the work that has already been published: Óscar Geovani Martínez-Cortés, Kant, S., & Isufllari, H. (2022). An analysis of wood availability under six policy scenarios of commercial forest plantations in Colombia. Forest Policy and Economics, 138, 102722[56].

Abstract

An empirical analysis which compares Colombia's 2019 Forest Plantation for Wood Production Value Chain policy (PFCm policy), aimed at reaching 1.5 Mha of commercial plantations by 2025, with five other policy scenarios, for the period 2015–2047, is presented. We consider two cases

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56 doi:https://doi.org/10.1016/j.forpol.2022.102722. Some minor changes were made to the original paper to adapt it to numbering and the flow of this thesis document, added texts are in squared brackets. **Contributions of authors to the paper:** Oscar Geovani Martinez-Cortes: Research conceptualization; data collection and curation; data analysis and model building; programming, model validation; visualization; and writing - original draft, and revisions as per comments & editing. Shashi Kant: Intellectual and theoretical inputs on research conceptualization; data requirements and curation; data analysis and model building, model validation; and different versions of the manuscript. Henrieta Isufllari: Support in data collection, policy analysis, preparation of the first draft, editing, and incorporation of the reviewers' suggestions. Acknowledgements: This research was made possible with the financial and non-financial support of the Graduate Department of Forestry, University of Toronto, Unidad de Planificacion Rural Agropecuaria de Colombia (UPRA), and the research grant of the 2nd author from Natural Science and Engineering Research Council of Canada, [RGPIN-2019-05199]. The authors would also like to acknowledge the valuable inputs/ suggestions of the first author's Ph.D. supervisory committee members and William F. Hyde and the valuable support at UPRA received from Felipe Fonseca, Daniel Aguilar y Alejandro Florez, and Luis Fernando Parra, specifically to Mr. Parra in building the simulator and programming in R, and the comments on the original draft and editing of the paper by Ximena Laverde. The authors would like to express our appreciation for the constructive comments and suggestions made by the two anonymous reviewers. We are also thankful to the Editor for his valuable suggestions and the support during the review process.

with no expansion, and two alternative goals for expansion reaching 0.765 Mha and 2 Mha, and compare the projected volume available for supply of wood with current and projected market demand. The exercise was conducted by designing and using the Colombian Forest Plantation Growth and Yield Simulator for predicting volume available for the supply of the country's unprocessed wood market, and as a consequence, the manufactured wood forest product market. No-expansion scenarios are non-viable options for the current state of the market, while among the expansion paths considered, both the PCFm policy goal and the 2 Mha scenario produce desirable results. This empirical exercise could be useful in quantifying the magnitude of the wood shortage concerns already identified by the PCFm policy, and provide policy makers and other stakeholders with a more precise framework for adequate action.

6.1 Introduction

Colombia is a tropical country endowed with rich forest resources, including an estimated 25 million ha (Mha) of available area for the development of commercial forest plantations. However, in the past few decades, the Colombian forest sector has been underperforming, characterized, among other things, by high rates of deforestation and natural forest degradation, and difficulties in supplying from its national sources the forest products demanded. Currently, the country is redesigning its forest policy and implementing, with help from the international community, several forest initiatives to boost the forest sector, but no analytical tools for the forest sector, such as growth and yield simulation models, are available to the stakeholders involved in these processes for analyzing the impact of these policies.

Initiatives to restructure the Colombian forest sector have been in the works, more intensively, since the start of the current millennium. As part of the Government initiatives, the Ministry of Agriculture, the Ministry of Environment and Sustainable Development, the Ministry of Industry, Trade, and Tourism, and the Department of National Planning of Colombia released the National Forest Development Plan (PNDF for its acronym in Spanish), in the year 2000 (MMA et al., 2000). One of the main objectives of this plan was positioning the country as a key player in the international arena, with a strong presence and negotiating power over the most pressing topics in forestry: the use, conservation, and sustainability of its forest ecosystems, as well as international competitiveness of its wood forest products (MMA et al., 2000). An important motivator, at the time the PNDF was announced, was Colombia's heavily underused capacity for commercial forest plantations. By 1996, of the roughly 25 Mha estimated available area for commercial forest plantations, the country had utilized less than 2% for wood production; this, together with the degradation of national natural forest resources, resulted in a substantial negative trade balance of US$ 325 million for the Colombian forest sector, with exports at around US$ 66 million (Martinez-Cortes, 1998). In addition, country wide data on reforestation in the years preceding 2000, consolidated by Martinez-Cortes (2022), indicated low and stagnated rates, contrary to the upward trend observed worldwide for the same period.

The decades that followed the introduction of the PNDF did not present much change to the state of the forest sector and particularly the wood forest products industry, due, in part, to the delay with which some of the objectives and goals of this plan were being executed. Two examples of this were the slow implementation of the tasks to reach the goals of 1.5 Mha of commercial forest plantations under sustainable management, and the modernization and expansion of the wood forest products industry. As marginal results for these goals were obtained under the PNDF, and the negative trade balance for the Colombian forest sector continued to widen for all manufactured wood forest products (Martinez-Cortes, 2022), stakeholders called for action in the first half of the 2010s. This call ended up in the Agricultural Rural Planning Unit (UPRA – its acronym in Spanish) leading a two-year (2016-2017) consultation process, which involved more than 50 stakeholders partially to redesign the Colombian forest policy, resulting into what was called the Commercial Forest Plantation for the Wood Production (PFCm) Value Chain policy (PFCm policy - its acronym in Spanish).

The PFCm policy was only signed and officially released by the Ministry of Agriculture and Rural Development of Colombia (MADR) in June 2019. This policy is set to be implemented in three time-periods during the next 20 years: 2018-2022, 2023-2030, and 2031-2038, each period to be evaluated against the original objectives (MADR, 2019a). Comprising a set of policy guidelines and an action plan, the policy aims to continue to develop and consolidate the PFCm value chain, an initiative which originated in the middle of the 1950s (Martinez-Cortes et al., 2018a) and, by 2016, was the main source of raw wood for the Colombian forest industry, and within the same year, it generated about 40,000 direct jobs in forest plantations activities alone (MADR, 2017a). At that stage, the total available commercial forest plantation area comprised 0.3 million hectares, translating into a yearly production volume of around 3.0 million cubic meters of underbark unprocessed roundwood (Profor, 2017).

One important commitment of this policy, agreed upon through collaboration with the private sector stakeholders, was to continue with the expansion of commercial forest plantations until it reached 1.5 Mha by 2025, the same goal of the PNDF. By focusing on increasing the supply of wood forest products, this policy plans to address two issues related to growing the country's GDP through the forest sector: increase the international market share of Colombian exports and meet the projected increase in national demand. Estimates for the country's per capita consumption of wood forest products put the increase in demand for these products at 30% by 2030, and at 50% by 2038, both compared to 2013 levels (Martinez-Cortes et al, 2018b). The same study also estimated an increase of 20% in the productivity upon successful implementation of the PFCm policy, compared to 2016 levels, as well as an increase in the quality of its wood forest products, on par with international levels.

Another important area of the Colombian economy expected to benefit from the PFCm policy is the labour market, which is projected to experience an increase of up to 500,000 new formal jobs by 2030. Of these, around 127,000 will be from the commercial forest plantation expansion and its sustainable management, and the rest will be indirect jobs, related to the transportation, the traditional wood forest products industry, and the commercialization of wood and manufactured wood forest products. Additional jobs are expected to be generated from the expansion of innovative wood forest product industries, such as bio composites, and those belonging to the cosmetics, and the food industry, to name a few.

The environmental sustainability aspect of the PFCm policy promises to increase sustainable forest management through a full certification of its practices related to the establishment, management and harvesting, and of the chain-of-custody standards of the wood produced in these plantations. By the end of 2016, the Forest Stewardship Council (FSC) database reported that only around 143,000 ha of the total commercially forest planted area was FSC certified. By that year, there were no other certification programmes for forest plantations in Colombia. In addition to increasing the commercially planted area to 1.5 Mha, the PFCm policy plans to reach a certification level of 80% of this area by 2030, and an 80% certification of the chain-of-custody standards for its forest products by the same year (Martinez-Cortes et al., 2018b). The contribution of this level of certification is expected to span from protecting Colombia from deforestation and illegal logging of its vast natural forests to improvements in water quality, biodiversity protection, as well as much needed reductions in the carbon footprint.

The PFCm policy comprises 12 different programs and 30 projects necessary for its successful execution. The total cost of its implementation, without considering industry modernization and expansion, was budgeted at US$ 1.73 billion, 35% of which will come from the public sector, 64% from the private sector, and the rest from international aid. The majority of these costs are allocated to the expansion of the current (2016) commercial forest plantations to 1.5 Mha and their management. Out of the total cost of US$1.73 billion, the cost of commercial plantations is estimated US$ 1.7 billion, 65% of which will come from the private sector stakeholders invested in the initiative, and 35% from the government budget (Martinez-Cortes et al., 2018a).

Aside from the importance of such policy to both the private sector and the economy as a whole, a more detailed look at the implementation of the 1.5 Mha of the PFCm goal suggests that it was defined without a clear, transparent, and analytical analysis of the impacts that the development of forest plantations of such magnitude would have on the wood forest products markets, and the manufactured wood forest products industry as a whole[57].

A good first step towards better insight on the potential impacts of such policy would be a rigorous estimation of the additional volumes of wood added to the market. The heterogenous and multidimensional composition of the source of wood, and the industry that utilizes it make the calculation of volume production from the commercial forest plantations fairly complex. As of

[57] The Colombian wood forest product markets comprise two markets: the unprocessed wood markets and the manufactured wood forest products markets. The manufactured wood forest products industry includes the wood industry, the furniture industry and the pulp and paper industry. The Colombian wood industry comprises the sawnwood industry; the wood-based panel industry; roundwood industry for poles, piling, posts, etc. preserved or not; and the industry that elaborates a series of manufactured wood products such as moulding and pallets. In this paper, the traditional manufactured wood forest products industries of pulp, wood-based panel other than veneer and plywood, jointly with the innovative manufactured wood forest products industries (forest bioenergy, bio-composites, and derivates from wood for the chemical, cosmetic and food industries) are grouped under the acronym of CITPI.

2015, the commercially planted area comprises uneven aged plantations of more than 20 distinct species, planted by large, medium, and small landholders (Profor, 2017)[58]. These species are planted in different geographical areas, and as such, their productivity levels are subject to variations in soil composition, as well climate and other environmental conditions. At the management level, the plantations serve different production objectives, such as wood, fiber, bioenergy, and non-wood/wood forest products. Given that such variation is present in both within the same planted area or between two or more different areas, this, in turn, has generated multiple forestry management regimes. The PFCm policy plans to achieve the 1.5 Mha goal by expanding most of the country's current commercial plantation areas. It will do so through the planting and management of 16 of more than 20 existing species, specifically the ones with the highest production efficiency[59]. In doing so, the additional plantations inherit the same complexity as the current ones.

As a result, there is an imminent need for a dynamic and comprehensive analysis that uses a systematic and robust way of predicting the volume increase upon the implementation of the expansionary policy, which can be utilized by policy makers when evaluating the policy implementation results. In this paper, we provide such analysis through an exercise that evaluates the results of the proposed 1.5 Mha expansion plan of the PFCm policy and five other commercial plantation expansionary paths, for comparison with the ability of said policy to satisfy projected quality-based demand from each wood product industry.

In order to conduct our analysis, we developed the Colombian Forest Plantation Growth and Yield Simulator (SCRPFC, by its acronym in Spanish) using the site- quality and species-specific data from the existing commercial plantations. This simulator was designed as part of the Colombian Forest Sector Model (CFSM) which is the main part of the Ph.D. thesis of the first author. The Simulator estimates volume available for wood supply, and uses it to calculate the expected volume of wood for different industrial use, that will be useful to policy makers during their

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[58] For a 2021 up-to-date distribution on commercial forest plantation area in Colombia refer to MADR (2021). The breakdown of this area by species in 2015 and 2020 is almost the same.

[59] *Pinus caribaea, P. maximinoi, P. oocarpa, P. patula, P. tecunumanii, Eucalyptus camaldulensis, E. grandis, E. pellita, E. tereticornis, E. urophylla, Tectona grandis, Gmelina arborea, Acacia mangium, Cupressus lusitanica, Pachira quinata y Ochroma pyramidale* (Martinez-Cortes et al., 2018a).

evaluation stage of the policy. We compare the results of six expansion scenarios of commercial forest plantations and discuss their implications for wood supply to forest industry.

The rest of the paper is organized as follows: Section 6.2 presents the literature review. Section 6.3 introduces the methodology and the simulator. The theoretical details of the simulator are given in Appendix 6-1. An empirical exercise comparing six expansion scenarios as well as the results of the exercise are presented in Sections 6.4 and 6.5. We discuss the findings and conclusions in Section 6.6 and include some final thoughts and future research in Section 6.7.

6.2 Literature review

Projecting the future availability of wood supply on a national scale is the key to analyzing a country´s long-term forest industry development and the supply and demand of forest products markets. This is one of the reasons why, during the twentieth century, many countries in the world (especially in Europe and North America), implemented forest resource monitoring systems, started nation-wide assessments and later on developed wood availability projection systems that include mostly country-specific tools, models and simulators (Barreiro et al., 2017a).

The important features of these projection systems are growth and yield models. These models, which are the representation of an average growth of trees (Salas et al., 2016), are used to predict stand of tree development through time (Twery, 2004). These models can be classified as follows: yield tables, aggregated level (also known as stands-level) models, and individual-tree models (Munro, 1974; Salas et al., 2016; Vargas et al., 2016).

The yield tables represent the average value of a stand’s variables (Salas et al., 2016). These are the oldest approach to predict the growth of an even-aged forest, with the first published yield table published in Germany in 1787 (Vanclay, 2014). With the continuous development of statistics, yield tables have improved, and by incorporating equations that describe variables through time, they have become a reliable method (Vanclay, 2014). On the other hand, stand-level models use the stand as a single model unit, projecting the number of trees, basal area, or volume per stand based on information on age, stand density and site index (Barreiro & Tomé, 2017). Although these models omit variations within the stand, they are widely applied around the world (Härkönen et al., 2010). An example of the former are the growth and yield prediction models for various silviculture regimes, based on large databases of experimental data from large-scale industrial pine plantations in southern US, developed by the Plantation Management Research Cooperative at University of Georgia in collaboration with the forest industry. Aside from considering growth and yield responses to several silvicultural management regimes, the co-op's work has extended the analytical framework of yield prediction to evaluate productivity and profitability of forest plantations by constructing a profit function for timber production, which offers additional information about the production of this commodity (Yin et al., 1998).

Stand-level models are divided in matrix models and models based on probability density function (Salas et al., 2016). Finally, individual-tree models project the diameter and height increments of individual trees, taking into account variables such as tree size, age of stand, stand density and site index. They can also be classified as spatial or non-spatial models (Barreiro & Tomé, 2017).

Another key feature of projection systems are the simulators which range from standard simulators that combine forest inventories and yield tables to complex ones that include a national inventory database and functions/algorithms, which provide helpful information on forest management and assist policy making decisions (Barreiro & Tomé, 2017; Härkönen et al., 2010). An overview of differences between projection systems implemented in Europe and North America are described in depth by Barreiro et al. (2017b).

In South America, and specifically in the Neotropics which includes Colombia, the literature does not report the existence of national projections systems, but only that of specific simulators for some of a country's regions and species available. Among those, one of the most relevant works has been done in Chile, through two simulators: Nothofagus (Martin et al., 2020) and AMPL-CPLEX (Büchner et al., 2019; Instituto Forestal, 2013), aimed at both native forest and plantations (Pinus radiata, Eucalyptus spp. and Pseudotsuga menziesii), respectively.

In the Neotropic region, SILVIA from Costa Rica was created to manage and model the growth of Tectona grandis and Gmelina arborea at a stand-level or stand group, including species criteria, site index, thinning programs and growth scenarios. It is open to the public and comprises many equations that users can choose, and recently it is also being used for other species from natural forests (Serrano et al., 2008). In Panama, a simulator using an IPTIM (Integrated Planning for

Timberland Management) Assets software and SIMO (SIMulation and Optimization framework), where plot inventories are processed to obtain tree-level volume models, taper curve models and stand-level yield models, is designed to describe forest dynamics, project growth and yield, and support decision-making in Teak plantations (Seppänen & Mäkinen, 2020). Another simulator for Tectona grandis was built using SIMILE in Venezuela, with the purpose of obtaining growth of plantations, harvest volume and carbon sequestration capacity based on quality index, initial density of plantation and thinning regime (Jerez et al., 2015).

In Colombia, there exist some simulator-like tools for estimating the growth and yield of forest plantations, but the majority of them tends to be not as elaborate, or are limited to a particular species, parameter and geographical scope.

For example, López et al. (2007) have worked on models for forecasting growth and yield based on basal area and volume, to determine the optimum rotation age of Pinus caribaea in the Orinoquia Region in Colombia. Restrepo (2010), developed an empirical model based on the Bertalanffy-Chapman-Richards model, aimed at describing the yield and growth of Tectona grandis and Pinus patula in the Norwest Region in Colombia, specifically in Antioquia, Córdoba and Sucre Departmentos (an administrative and political divisions of Colombia is called Departamento, in Spanish), considering age and environmental covariables.

Barrios et al. (2014) developed equations of total volume and ratio for Eucalyptus grandis, using data from 101 trees collected in plantations located in Quindio Departamento (Central Region of Colombia). López et al., (2015) have developed some models of trunk profiles with an autoregressive structure for errors for Eucalyptus tereticornis growing on the country's Caribbean region and, Melo & Lizarazo (2017) developed equations to estimate tree volumes by applying a single taper polynomial function.

The most complete growth and yield simulator for the Colombian forest plantations is the SimFor v 1.2 Software, which was developed in 2013 by the Institute of Informatics of Southern University of Chile (UACh) for Colombia´s National Corporation of Forestry Research and Development (CONIF), for which growth and yield models were calibrated with five-year consecutive data coming from 700 permanent plots, distributed all over the Colombian forest plantations. Models were developed at a stand level, disaggregated to diameter classes. The simulation uses three transition functions (number of trees, basal area and dominant height) as algebraic difference equations. As state variables are known at any given age, the number of trees under each diameter class is estimated by recovering the parameters of a Weibull function. A height-diameter function predicts the height of the mean tree in each diameter class. Then, a taper function is used to predict the total volume grouped by products at each diameter class. Although powerful, there are two main issues that arise with SimFor: the institution (CONIF) which owns the software does not make it available for independent and academic research, and the use of a Beta version of the software with restricted features is not feasible, as the information needed to perform the simulations (i.e., state variables for each stand comprising the total mass of commercial forest plantations on December 31st of 2015, or for any other time period is not yet available).

In summary, given that no other viable option exists for the Colombian forest sector, the development of a proper growth and yield simulator was instrumental for evaluating wood supply implications of the proposed 1.5 Mha expansion plan of the PFCm policy and other commercial plantation expansionary paths.

6.3 Methodology

The SCRPFC is a tool that facilitates projections of the growth and yield for any stand in the commercial forest plantations. For the purpose of the SCRPFC and our paper, a stand is an area of commercial plantation homogeneously planted with trees belonging to one type of species, all at the same age, and within the same location. This classification is intended to minimize the noise in the data originated from all the variations mentioned in the introduction such as age, species, and site-quality.

The simulator can be described in three stages of operations: (i) the calculation of total growth at a stand level at any given year; (ii) the estimation of distribution of each year's growth by diameter class; and (iii) the determination of the current volume of available stock appropriate for harvesting in order to wood supply to different forest industries. Generally, in the first stage, the transition equations for stand density, dominant height, and basal area are estimated. In the second stage, growth parameters and volume are calculated for each diameter class. In this estimation, first the parameters of a probability function, Weibull distribution in our case, are calculated to find the number of trees in different diameter classes. After that the dominant diameter and the mean height are calculated for each diameter class, and the calculated value of the mean height and the diameter are used to calculate the total volume in each diameter class at a given point of time (year). In the third stage, using the volume taper model, the volume of available wood of different under-bark diameters (which is commonly used to measure industrial wood) is calculated. The technical details of all three stages are given in Appendix 6-1.

The three stages above represent the simulation steps at a theoretical level. Given the heterogeneity in species type, tree shape, and geographical location of the stands, additional adjustments were required, which include the following: For stage one we used the 52 growth and yield tables generated and already available in the Program on Forests (Profor) project of the World Bank on Colombia (Profor, 2017); while for stage three, we utilized the species-specific taper equations developed by López et al. (2011), with data from the permanent plot network of the commercial forest plantations in Colombia [Appendix 6-2].

6.4 Empirical exercise [VAS Estimation]

The Profor report, published by the World Bank in 2017, estimated the existing commercial plantations of 0.3 Mha, by the end of 2015. The Profor report estimated this area based on Colombian Agricultural Institute's (ICA by its acronym in Spanish) database of official registration of commercial forest plantations (Held et al., 2017). The Profor dataset is the only database that includes the disaggregated data of commercial forest plantations (that includes species, location, site quality, municipality, administrative division (which is also called Departmento in Colombia), and region for each plantation stand). A new database which includes all these and other features up to the end of 2021 is now being prepared under the Ph.D. research of the first author. In addition, one of the distinguishing features of our Simulator, compared to other simulators, is that it incorporates the ICA database, which is regularly updated as per registration requirements implemented in 2019 (MADR, 2019b).

The Colombian state reported the commercial plantation area of 0.45 Mha by December 2015 (MADR, 2017b), and about 0.5 Mha as of June 2021. However, the MADR dataset, that reported area of 0.45 Mha, is disaggregated only to the levels of species and administrative district. In addition, the MADR results had not been independently reviewed, while the Profor data was supervised by World Bank specialists. Hence, this dataset does not have sufficient disaggregation for the use in simulation exercises.

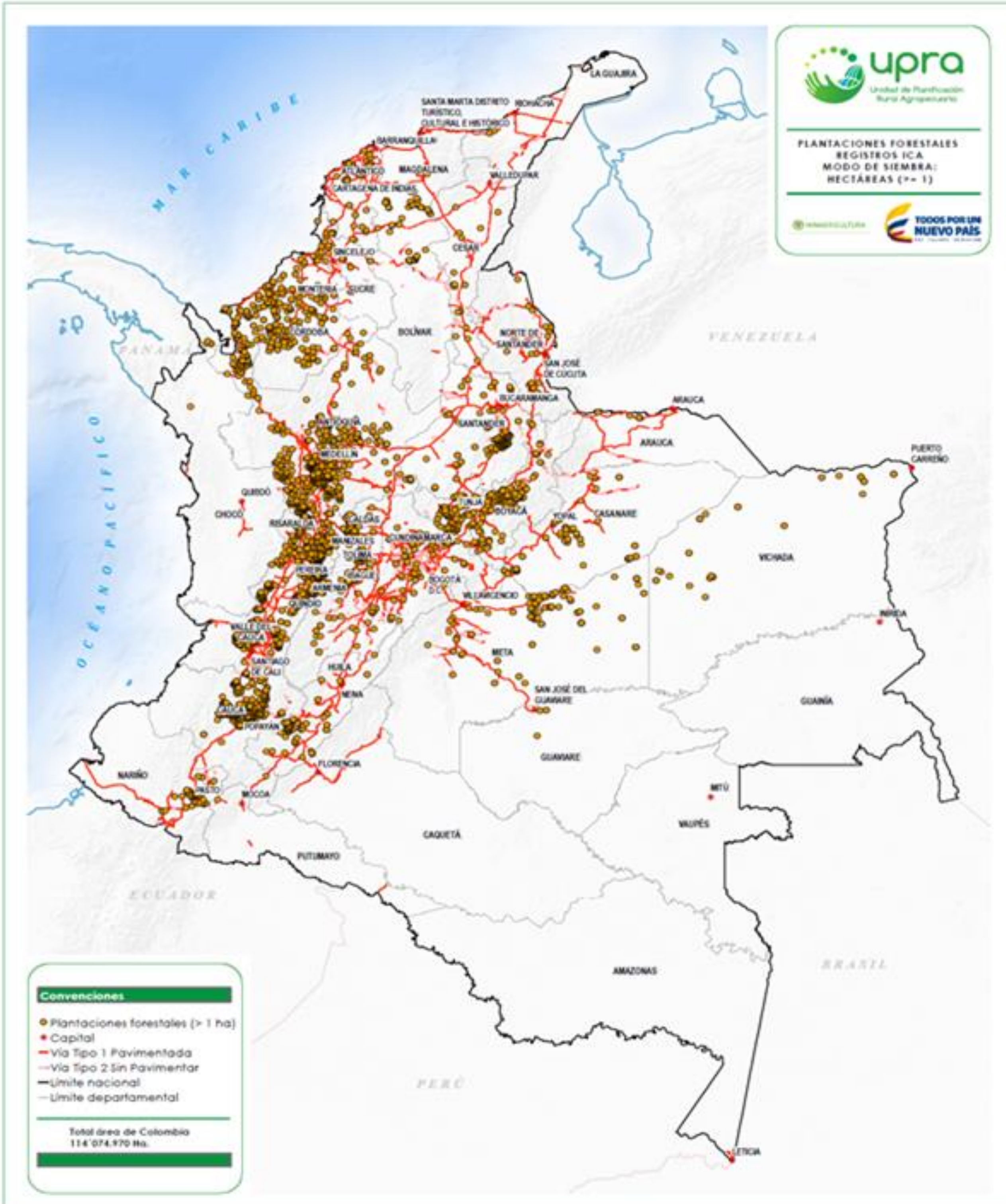
We, therefore, use the Profor dataset as the base for our analyses of different scenarios. The Profor dataset is only available for the period until December 2015, and therefore we use 2015 as the initial year of our analysis. To account for the reported figure of 0.45 Mha plantations in 2015, as per the MADR data, we use it as a base for one of our six scenarios.

A map of the commercial forest plantations, as per the Profor report for 2015, in Colombia is presented in Figure 6-1. A breakdown of this area into species, and administrative districts and regions is shown in Figures 6-2 and 6-3, respectively. As mentioned earlier, in Colombia, the administrative unit is called Departamento in Spanish which we are referring as department/division. The boundaries of different departments are shown in Figure 6-1.

Next, we identified six scenarios. For all scenarios, we assumed that the main objective of all commercial plantations is the production of wood. It was also assumed that all plantations are thinned and subjected to final harvesting at the age indicated by the growth and yield model of each forest species and site-class considered. For the first two scenarios, we assumed that there is no increase in the commercial plantation area either by public or private sector. In other words, the objectives of the PFCm policy to increase commercial plantations are not executed. In the base scenario or Scenario 1, we assumed that 301,146 ha of commercial forest plantations in 2015, as per the Profor report, is maintained in perpetuity. In Scenario 2, we assumed that 450,000 ha of commercial forest plantations in 2015, as per the MADR report, is maintained in perpetuity. For Scenario 2 modeling, 301,146 ha of Scenario 1 was used as the base and the difference plantation area of 148,584 ha was assigned proportionally to the departments and species to the commercial forest plantations in which plantations of Scenario 1 were registered in 2015. We call these two scenarios as no growth scenarios.

Next three scenarios are growth scenarios. In these scenarios, the initial plantation area (0.3 Mha) is incremented, starting in 2016, in order to reach 0.765 Mha in 2035 (Scenario 3), 1.5 Mha in 2025 (Scenario 4), and 2.0 Mha in 2025 (Scenario 5), respectively. The scenario 3 (0.765 Mha) is

Figure 6-1 Geographical distribution of Colombia's commercial plantations on December 31, 2015



Source: UPRA, 2017. Not official, without scale. Yellow dots: the forest plantation stands. Red lines: major highways. The name of political and administrative divisions of Colombia (departaments) are printed in black capitalized letter with their corresponding capital city signaled by a red dot.

Figure 6-2 Colombia´s commercial plantations on December 31st, 2015, by species, in ha.

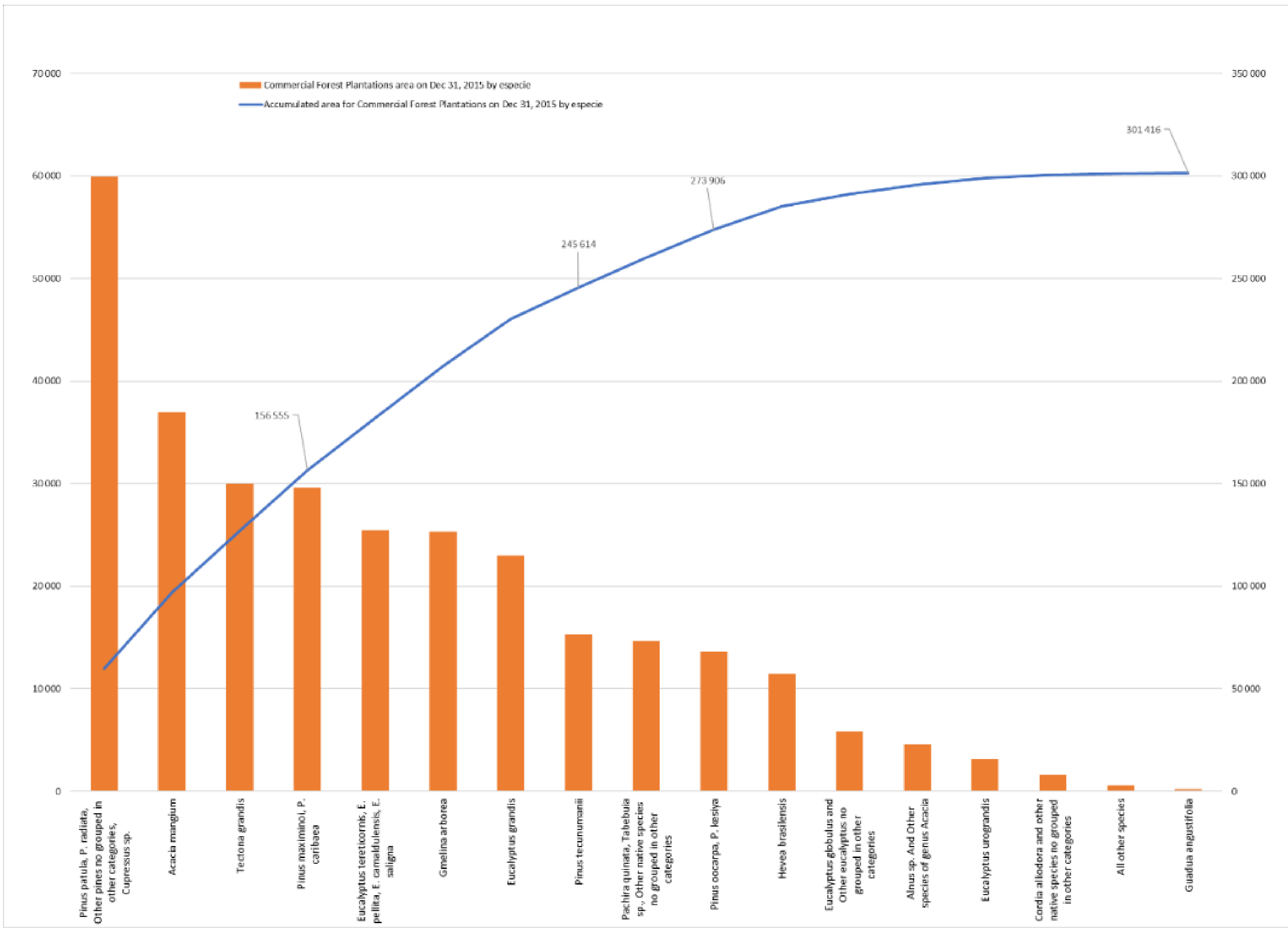
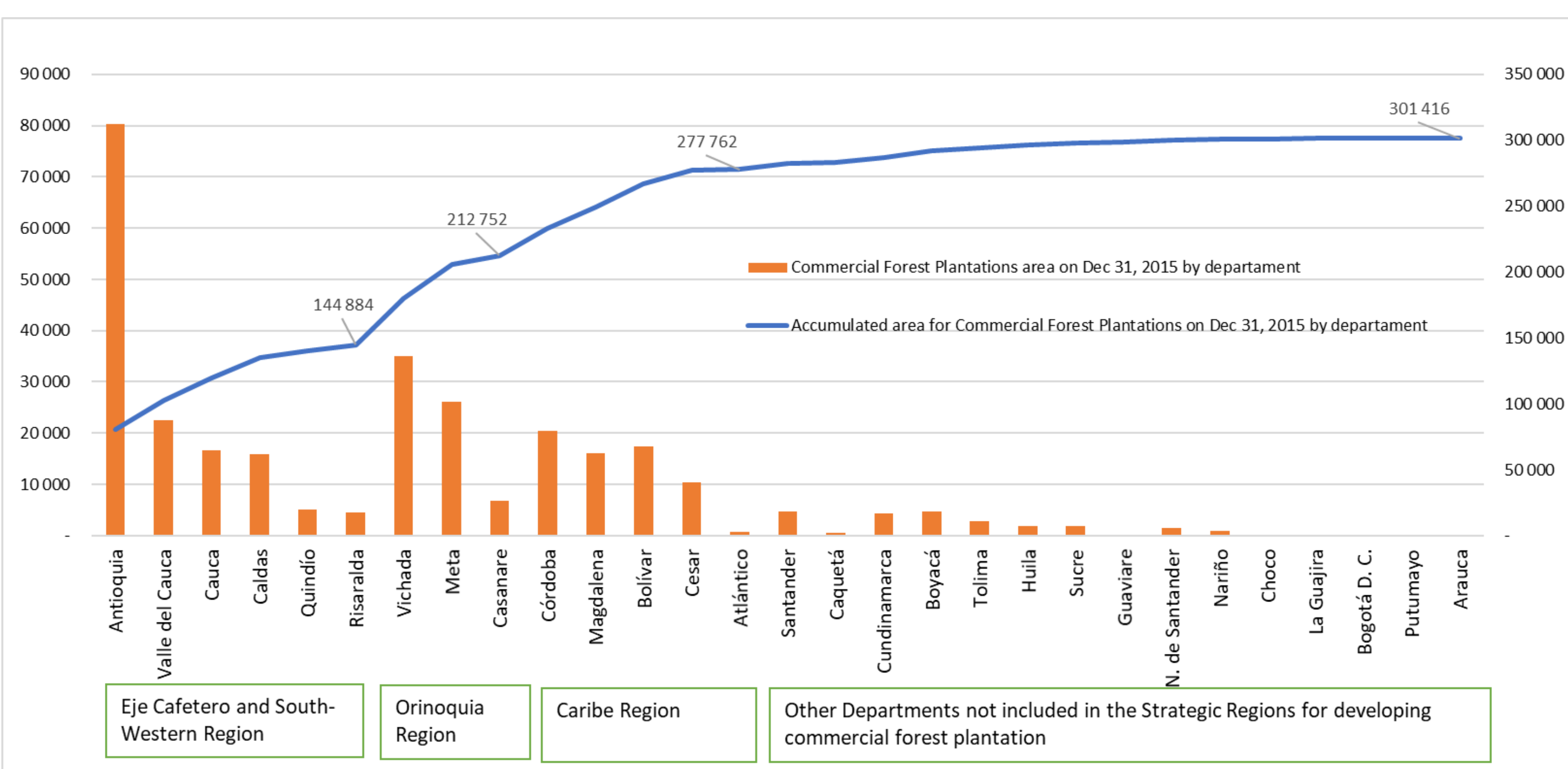


Figure 6-3 Colombia´s commercial plantations on December 31, 2015, by administrative divisions (departments) and regions, in ha.



the goal for commercial forest plantations for wood production that Colombia should have under sustained forest rotation, suggested by Profor (Held et al., 2017). The scenario 4 (1.5 Mha) is the goal set by the National Forest Development Plan in 2000, expected to be reached by 2025 (MMA, et al., 2000), which is also the goal for the 2019 PFCm policy (Martinez-Cortes et al., 2018b), while the scenario 5 is an alternative goal to the scenario 4. In all these five scenarios, the initial area and the target area are maintained under sustained rotation (i.e., the initial area and the target area never decrease).

The sixth scenario is about no new plantation and the harvest of the initial plantation area (0.3 Mha in 2015) starting in 2016 without replacement; consequently, the commercial plantation area eventually diminishes to zero. The key features of all six scenarios are presented in table 6-1.

Table 6-1 Scenario simulations for expansion of commercial forest plantations in Colombia.

SCRPFC Scenario Simulation Description	Scenario Code	Observations
NO INCREASE in the existing area of commercial forest plantations on December 31, 2015 (BASE SCENARIO at 301,146 ha)	S1: PROFOR2015	Total area of commercial forest plantations of 301,146 ha is maintained in perpetuity (that is, once an area undergoes the final harvest, an area of equal size must be established within forest plantations).
NO INCREASE in the existing area of commercial forest plantations in Colombia (BASE SCENARIO at 450,000 ha)	S2: MADR2015	For modeling purposes, the base of 301,146 ha of the PROFOR2015 scenario was used and 148,584 ha were assigned proportionally (in addition to other criteria) to the departments and species in the commercial forest plantations in which these were registered in 2015. Total area of commercial forest plantations of 450,000 ha is maintained in perpetuity.
INCREASE of the existing area of commercial forest plantations to 765,000 ha (Completion date: December 31, 2035)	S3: PROFOR2035	Area proposed by the Profor project. Profor's proposal includes increases in plantation yields and the establishment of 463,584 ha of new pine and eucalyptus plantations at an annual rate consistent with the historical trend of annual establishment of commercial forest plantations in Colombia. For modeling purposes, the base of 301,146 ha of the PROFOR2015 scenario was used and annual stands were added for pine and eucalyptus species in the departments where the plantations were located in 2015. Total area of commercial forest plantations of 765,000 ha is maintained in perpetuity.
INCREASE of the existing area of commercial forest plantations to 1,500,000 ha (Completion date: December 31, 2025)	S4: PNDF/ PAPFCm1	Proposed area of the National Forest Development Plan-PNDF, to be reached by 2025. This proposed goal is the same as the one in the PFCm policy, developed by UPRA. For modeling purposes, the base of 301,146 ha of the PROFOR2015 scenario was used and, as of 2015, annual stands were added for 16 species in 14 departments located in the 3 strategic development regions for forest plantations for commercial purposes defined in the Policy Guidelines of the PFCm chain. Total area of commercial forest plantations of 1,500,000 ha is maintained in perpetuity.
INCREASE of the existing area of commercial forest plantations to 2,000,000 ha (Completion date: December 31, 2025)	S5: PNDF/ PAPFCm2	Area proposed in the PNDF / PAPFCm1 scenario (S4 above) and an additional 500,000 ha; the annual planting rates between 2020 and 2025 revised accordingly. The total plantation area of 2,000,000 ha to be maintained in perpetuity.
DECREASE of the existing area of commercial forest plantations to zero ha	S6: PROFOR2015-SR	Scenario 1 without replacement of annual harvested area. The total area of plantations reaches zero in 2035. For the purpose of calculating the supply of wood, it has been assumed that the volume (both thinning and final harvest) that should have been harvested until December 31, 2015, and is still standing as of that date, will be harvested in equal quotas each year between 2016 and 2034.

6.5 Results

We run the Colombian Forest Plantation Growth and Yield Simulator (SCRPFC) for estimating the expected volume of wood available for supply from each scenario for the period 2015-2047. Wood available for supply from commercial forest plantations is the wood that would be obtained from a stand which is subject to thinnings and final harvest at the age that the management regime specifies for the species planted in such stand. The wood logs obtained from the thinnings and final harvest must comply, at least, with the minimum specification for industrial use. In 2047, all stands in scenarios S1 to S5 would have completed, at least, the first rotation period under sustained management (i.e., would have been subject to final harvest and been planted for second rotation).

A visual representation of the projected expansion area for the six scenarios is given in Figure 6-4. [Tables for] expansion of areas by year, species and geographical location are presented in Appendix 6-3 to 6-5.

Simulation results indicate that wood availability from commercial forest plantations for wood production during the simulation period would range between 71 and 868 million m^3 of underbark roundwood (Mm^3rsc, for its acronym in Spanish), depending on the simulated scenario. When the initial area for wood production diminishes to zero (S6), Colombia would only have a one-time supply of 71 Mm^3rsc of wood available for harvesting. When the plantation area increases to 2 Mha (S5) in 2025, which would then be maintained under sustained rotation, Colombia would have 868 Mm^3rsc of wood during the 2015 - 2047 period, and a similar quantity every 32 years, starting in 2047. The wood available for the period of 2015 – 2047, for the six simulated scenarios is shown in Figure 6-5.

Figure 6-4 Annual planted area of commercial plantations under six scenarios in Colombia

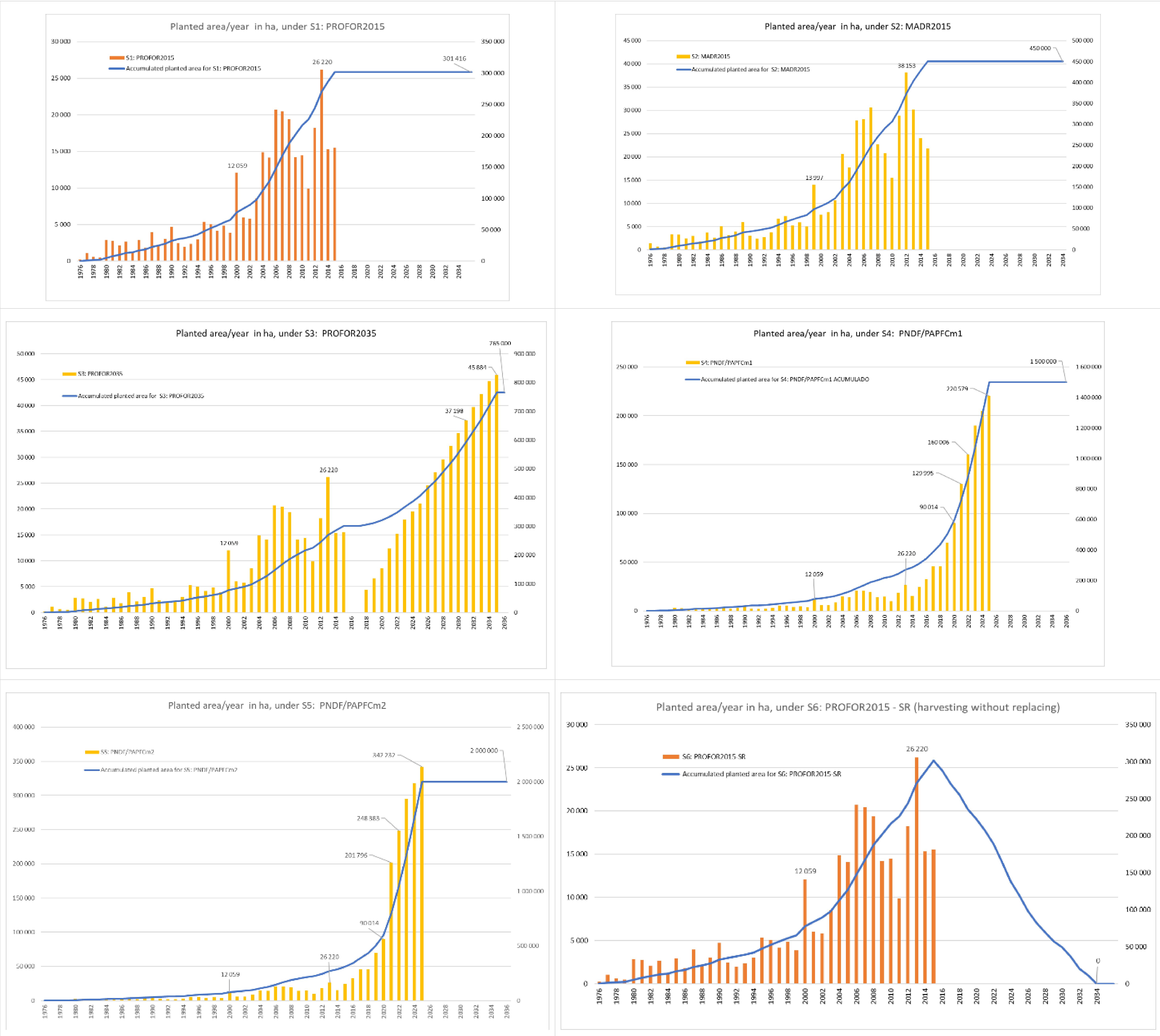
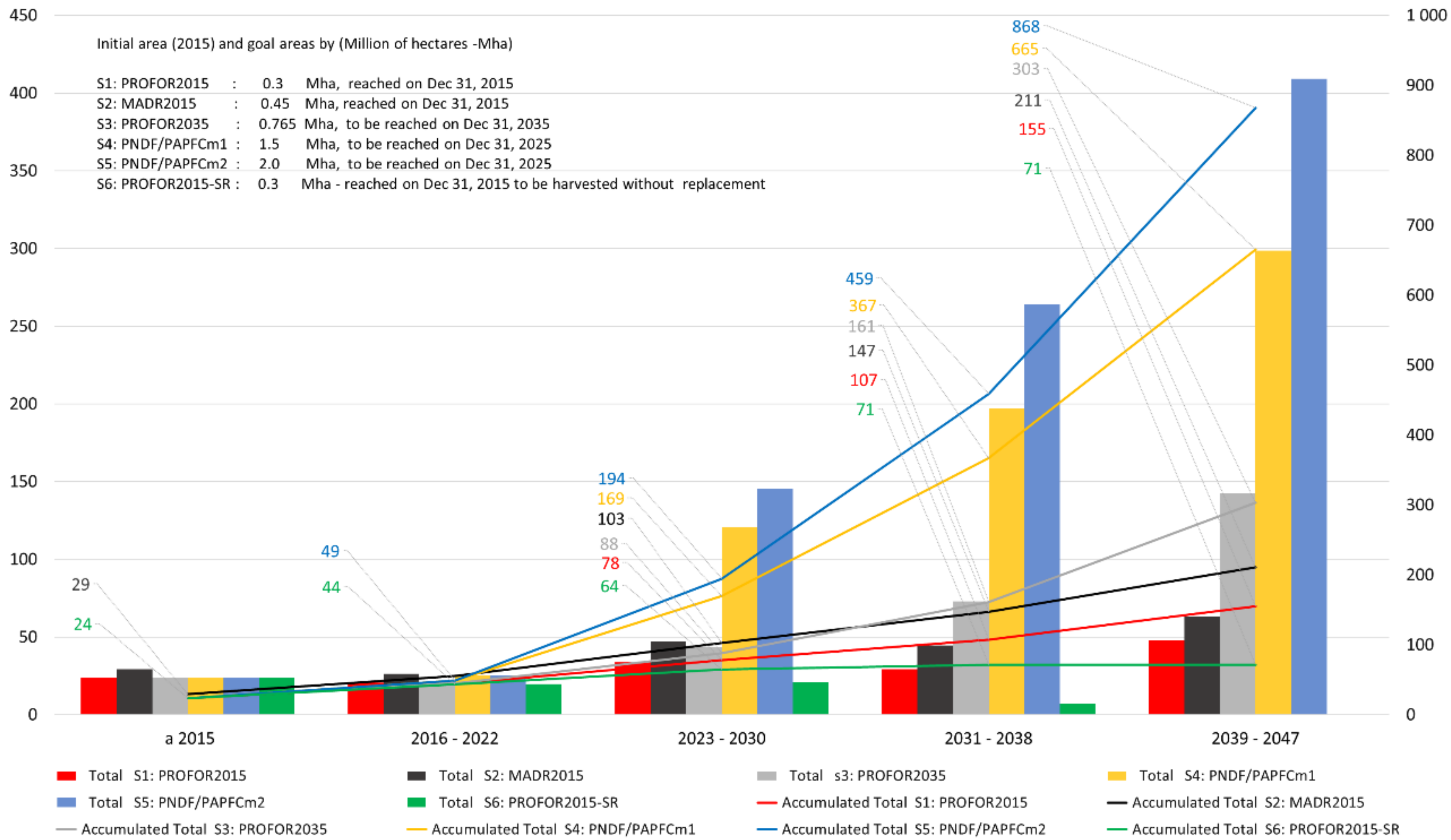


Figure 6-5 Availability of wood from commercial plantations under six scenarios in Colombia, 2015–2047 (million m^3 of underbark roundwood - Mm^{3}rsc)



The volumes in figure 6-5 were obtained by strictly applying the management regime to each stand that makes up the total area of commercial forest plantation in each one the six scenarios simulated. In other words, the volume was obtained by subjecting every stand to both thinning and final harvesting, at an age as per the guidelines outlined in the usual Colombian silvicultural model for each species considered in the simulation. It does not reflect any other harvesting done for satisfying actual or potential market demand for unprocessed wood. In addition, the calculations reflect volumes of stands which have not reached full maturity. For stands which, as of December 31, 2015, are already at full maturity or past it, we suppose that they are harvested at the same order as they were planted, starting with the earliest one being harvested in 2016[60].

Table 6-2 presents a more detailed information on the available volumes for supply for the period of the simulations, showing, among others, the average total annual volumes, stumpage volumes for matured, overmatured, and stands where full maturity has not yet been reached. Other indicators included in the table are the average of the additional volumes that are added for every expansionary goal after 2015, and volumes if the total forest plantations were a normal forest.

In the Colombian regional context (Figure 6-6), under S1 & S2, approximately half of the wood would be available in the Eje Cafetero y Suroccidente region, a quarter in the Caribe region, and 15% in the Orinoquia one. Meanwhile, for S4 & S5, around half of the wood would be available in Orinoquia, a bit over a quarter in Eje Cafetero y Suroccidente, and 20% in the Caribe region. In the S3 case, 38% of the total wood would be available in the Orinoquia region, 36% in Eje Cafetero y Suroccidente, and 21% in the Caribe region.

With regards to species types, between 55% and 78% of all the wood available would correspond to the wood of the species of genres *Pinus* and *Eucalyptus* for all the simulated scenarios. If wood from these species is added to wood of *Acacia mangium, Tectona grandis* and *Gmelina arborea*, they would account for 87% to 97% of all of the wood available in all six scenarios simulated.

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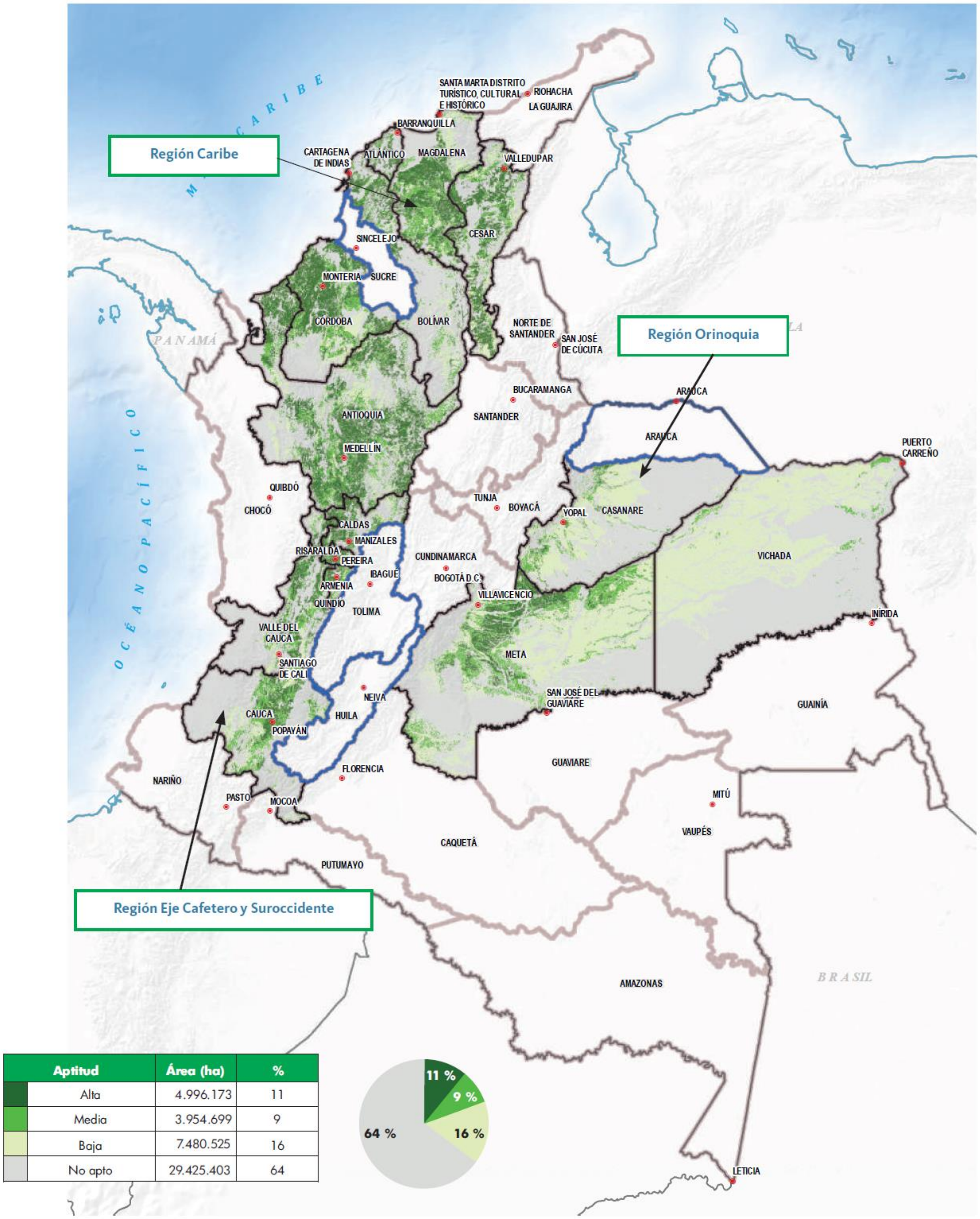
[60] A stand that has reached the age of final harvest according to the management regime for a species is considered a mature one. Detailed data on stands for scenarios simulated and the management regime applied [is found in Appendix 8-6].

Table 6-2 Wood available from commercial plantations for the six scenarios in Colombia (Period: 2015 – 2047; Volume unit: Mm^3rsc)

Scenarios	S1: PROFOR2015	S2: MADR2015	S3: PROFOR2035	S4: PNDF/PAPFCm1	S5: PNDF/PAPFCm2	S6: PROFOR2015-SR
Total wood available (A)	155	211	303	665	868	71
Annual Average of (A) above	4.8	6.6	9.5	20.8	27.1	2.2
Available volume of matured and over-matured stands on December 31, 2015	18	22	18	18	18	18
Available volume of not yet matured stands at December 31, 2015	6	7	6	6	6	6
Total availability of wood accumulated during 2015-2047, without the initial volumes on December 31, 2015 (B)	131	182	279	641	844	47
Annual average of (B) above	4.1	5.7	8.7	20.0	26.4	1.5
Annual average of wood available if the forest under sustained rotation had been normalized (Normal Forest) in the period 2015-2047	5.1	7.4	13.6	26.1	34.8	N/A

Figure 6-6 Strategic development regions' potential area for forest plantation development under the PFCm policy



Aptitud	Área (ha)	%
Alta	4.996.173	11
Media	3.954.699	9
Baja	7.480.525	16
No apto	29.425.403	64

Source: UPRA, 2017 [taken from Martinez-Cortes, 2018b]. Dark green: the best potential areas; Light green: the second-best potential areas; and Lighter green: the third-best potential areas.

Table 6-3 Annual average availability of wood from commercial forest plantations for the six scenarios in Colombia (By harvest type and industrial use); All volume values in Mm^{3}rsc

Scenario	Harvest type	Industrial use*	Sub-Period 2015	2016–2022	2023–2030	2031–2038	2039–2047	Total 2015–2047	Percent
S1: PROFOR2015	Total		0.7	3.0	4.2	3.7	5.3	4.8	100
	Final harvest	High quality sawnwood	0.2	1.0	1.9	1.2	2.3	1.9	39
		Low quality sawnwood	0.1	0.6	0.9	0.8	1.2	1.0	21
		Wood-based pannels, pulp, and forest bioenergy	0.1	0.5	0.7	0.7	0.9	0.8	16
	Thinnings	Wood-based pannels, pulp, and forest bioenergy	0.3	0.8	0.7	0.9	0.9	1.1	23
S2: MADR2015	Total		0.9	3.7	5.9	5.6	7.0	6.6	100
	Final harvest	High quality sawnwood	0.3	1.3	2.5	1.9	3.0	2.5	38
		Low quality sawnwood	0.2	0.8	1.3	1.3	1.6	1.4	22
		Wood-based pannels, pulp, and forest bioenergy	0.1	0.6	1.1	1.1	1.3	1.2	18
	Thinnings	Wood-based pannels, pulp, and forest bioenergy	0.4	1.0	0.9	1.2	1.2	1.4	22
S3: PROFOR2035	Total		0.7	3.0	5.4	9.1	15.8	9.5	100
	Final harvest	High quality sawnwood	0.2	1.0	2.1	2.5	6.5	3.4	36
		Low quality sawnwood	0.1	0.6	1.1	1.8	3.6	2.0	21
		Wood-based pannels, pulp, and forest bioenergy	0.1	0.5	0.8	1.3	2.4	1.4	15
	Thinnings	Wood-based pannels, pulp, and forest bioenergy	0.3	0.8	1.5	3.4	3.2	2.6	27
S4: PNDF/ PAPFCm1	Total		0.7	3.6	15.1	24.6	33.2	20.8	100
	Final harvest	High quality sawnwood	0.2	1.0	3.2	7.2	13.0	6.7	32
		Low quality sawnwood	0.1	0.6	2.6	6.1	8.2	4.8	23
		Wood-based pannels, pulp, and forest bioenergy	0.1	0.5	1.9	4.2	5.5	3.3	16
	Thinnings	Wood-based pannels, pulp, and forest bioenergy	0.3	1.4	7.3	7.0	6.4	6.0	29
S5: PNDF/ PAPFCm2	Total		0.7	3.6	18.2	33.0	45.5	27.1	100
	Final harvest	High quality sawnwood	0.2	1.0	3.4	9.4	18.0	8.7	32
		Low quality sawnwood	0.1	0.6	2.8	8.3	11.2	6.2	23
		Wood-based pannels, pulp, and forest bioenergy	0.1	0.5	2.1	5.6	7.5	4.2	16
	Thinnings	Wood-based pannels, pulp, and forest bioenergy	0.3	1.4	9.9	9.6	8.6	7.9	29
S6: PROFOR2015-SR	Total		0.7	2.8	2.6	0.9	0.0	2.2	100
	Final harvest	High quality sawnwood	0.2	1.0	1.5	0.5	0.0	1.0	43
		Low quality sawnwood	0.1	0.6	0.6	0.2	0.0	0.5	21
		Wood-based pannels, pulp, and forest bioenergy	0.1	0.5	0.5	0.1	0.0	0.3	15
	Thinnings	Wood-based pannels, pulp, and forest bioenergy	0.3	0.7	0.1	0.0	0.0	0.5	20

High quality sawnwood (Min. diameter > 20 cm), Low quality sawnwood (Max. diameter < 20 cm & min. Diameter > 15 cm), Wood-based panels, pulp, and forest bioenergy (Max. diameter < 15 cm & min. Diameter > 5 cm. * Industrial use has been defined based solely on the size of the logs for the industry of traditional primary wood forest products (sawn wood, boards and pulp), and excludes wood for energy from forest biomass, which is included within of the innovative wood forest products industry. Within the classification, no reference is made to the industry of traditional higher value-added wood forest products (eg. paper and cardboard, furniture, structures and wood carpentry and other products of secondary processing), since almost all the products of this industry go through the pulp, sawing and board industries.

The annual average availability of wood for different industrial use from commercial forest plantations for the six scenarios in Colombia is given in table 6-3. The table also includes the details of available wood from final harvesting and thinning.

6.6 Discussion, policy recommendations, and conclusions

For convenience, the analysis under this section is conducted in the absence of the wood supply from other Colombian sources (natural forests, agroforestry systems and trees outside the forest) and from imports of unprocessed wood. So, it is important to bear in mind that the way some findings are presented does not imply that in practice "it must be the case", but rather that the figures allow to present the findings in such fashion. This is an important issue for wood supply and capacity expansion of the Colombian sawnwood industry, when the levels of wood supply and expansion are related just to wood coming from forest plantations, although in reality half of the current supply for this industry comes from natural forests.

Also, the present analysis is done without taking into account the possible positive effects on timber supply from gains in productivity that may be derived from any additional foreseeable intensive plantation management other than the current ones applied to forest plantations in Colombia (e.g., additional improvements in competing vegetation control and fertilization) and any genetic improvement of trees. At present, this is not a common practice in the Colombian commercial forest plantation, and should this change in the future, the model presented in this paper will need to be updated in order to best capture the potential gains. This can be modelled by following the guidelines on how the supply of wood from forest plantations can be affected by these two strategies in Yin and Sedjo (2001) and Yin et al (1998), respectively.

6.6.1 Supplying and expansion of the manufactured wood products industry

6.6.1.1 No expansion (Scenarios 1 & 2)

Due to constraints related to the property and distance to the industrial facilities and markets, among others, for scenarios maintaining initial areas (0.3 Mha and 0.45 Mha) under sustained rotation, the actual availability of wood would be less than that shown in the simulation results in

Table 6-2 (less than 155, and 211 Mm^3rsc, respectively). Instead of being, on average, 4.8 and 6.6 Mm^3rsc/year (row two of Table 6-2), they would be 4.1 Mm^3rsc/year and 5.7 Mm^3rsc/year (row 6 of Table 6-2) for Scenario 1 and 2, respectively.

In 2017, the installed production capacity of the pulp, wood-based panels, and sawnwood industries, was estimated at 4.8 Mm^3rsc/year (1.0 Mm^3rsc/year for pulp, 0.8 Mm^3rsc/year for panels and 3.0 Mm^3rsc/year for sawnwood (Martinez-Cortes et al., 2018b)[61]. It can be seen that the volume generated by the initial area of 0.3 Mha is insufficient for providing wood that meets the 4.8 Mm^3rsc/year potential demand (at a 100% production capacity utilization) of the manufactured wood primary products industry i.e., woodpulp, wood-based panels and sawnwood industries. On the other hand, the 5.7 Mm^3rsc/year projected from the initial area of 0.45Mha, although enough to satisfy industry demand, does not allow for any considerable demand increases from the industry. In addition, as we mentioned earlier, the details of the figure of 0.45 Mha plantation area are not available at the same level as of the figure of 0.30Mha, and therefore the wood availability of 5.7 Mm^3rsc/year may be questioned. Hence, this makes the dilemma on which initial area to use of little importance for our discussion.

This shortage of wood was an issue already suspected during the redesigning process of the PFCm policy in 2017, but given that no actual calculations were performed, it was only mentioned in a rather descriptive fashion. One important contribution that we hope to provide with our simulations is that, now that the figures on wood availability from the initial area of forest plantation have become available, those stakeholders that argued that there is a shortfall in wood supply from the commercial forest plantations in Colombia can now back their argument by an empirical analysis.

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[61] In 2016 the wood supply of the Colombian woodpulp industry was provided entirely from commercial forest plantations; for the wood-based panels, it comprises wood mainly from commercial forest plantations and negligible amounts of sawndust and other sawnwood industry residues of wood from natural forests. The supply of wood for the sawnwood industry was made up by a mix of both sources: natural forests and commercial forest plantations, with an increasing share of wood from the latter source during the recent years (Martinez-Cortes et al., 2018b). Production capacity and expansion figures are referred to the equivalent cubic meters of roundwood excluding bark needed to produce an amount of manufactured wood products.

6.6.1.2 Three expansion paths (Scenarios 3-5)

Maintaining under sustained rotation the areas of 0.765 Mha (S3), 1.5 Mha (S4) and 2.0 Mha (S5), Colombia would have, on average, 9.5 Mm^3rsc/year, 20.8 Mm^3rsc/year and 27.1 Mm^3rsc/year, of available wood on its commercial forest plantations for wood production (14 Mm^3rsc/year, 26 Mm^3rsc/year and 35 Mm^3rsc/year, respectively, under the concept of Normal Forest)[62]. In the following 30 years, this raw material would allow for expansions of the sawnwood industry (with estimated current installed capacity of 3.0 Mm^3rsc/year) by approximately two, three and five times, respectively (three, four and six times when the forest mass in each scenario reach the behavior of a Normal Forest). To date, and to the best of our knowledge, there has been no expansion on installed capacity of this industry or the rest of the Colombian forest industries. Therefore, the simulations in this paper are performed using the above rate, without loss of generality. At the same time, the 9.5 Mm^3rsc/year, 20.8 Mm^3rsc/year and 27.1 Mm^3rsc/year (14 Mm^3rsc/year, 26 Mm^3rsc/year and 35 Mm^3rsc/year, under a Normal Forest) average production would allow for the expansion of the CIPTPI (group of industries of pulp, wood-based panels (boards), and innovative manufactured wood forest products), by approximately two, five and six its current (2017) installed capacity, respectively (four, six and eight times if the forest mass is a Normal Forest)[63].

Under S3, if the Colombian sawnwood industry remains at its current installed capacity (3,0 Mm^3rsc/year) and operates at full capacity, starting from the 2023-2030 period, its demand could be entirely satisfied with wood coming from commercial forest plantations (currently about 50% of its total supply comes from natural forests). This industry can also be expanded to a capacity production of 4 Mm^3rsc/year during the period 2031-2038, and then to 10 Mm^3rsc/ year during the

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[62] We also calculated the annual averages of wood availability using the concept of Normal Forest. The results are given in the last row of Table 6-2.

[63] Innovative manufactured wood forest products include forest bioenergy, forest bio-composites, and chemical, cosmetic and food products derived from wood, among others. As of 2017, innovative manufactured wood forest products industry in Colombia is negligible, so the current (2017) installed capacity of the CIPTPI is the sum of woodpulp and wood-based panels, i.e., 1,8 Mm^3rsc/year.

2039-2047 period. For the same time periods, the 2017- CIPTPI production capacity (1,8 Mm^3rsc/year) could be expanded near to 5 Mm^3rsc/year and 6 Mm^3rsc/year, respectively.

Under S4, the installed capacity of the sawnwood industry could increase to around 6 Mm^3rsc/year during 2023-2030, and to 13 Mm^3rsc/year during 2031-2038. At the same time, the CIPTPI could increase its installed capacity to 9 Mm^3rsc/year during the years between 2023 to 2030, and then to 11 Mm^3rsc/year during the years of 2031 to 2038.

Under S5, sawnwood industry expansion could reach 6 Mm^3rsc/year during 2023-2030, and up to 18 Mm^3rsc/year during the period of 2031-2038. In turn, the installed capacity of the CIPTPI could be expanded to 12 Mm^3rsc/year during 2023-2030, and then to 15 Mm^3rsc/year for 2031-2038.

In the previous paragraphs, we have projected industry expansion for S4 and S5 only up to the period of 2031-2038 while Table 6-3 shows a peak of production in period 2039-2047. However, when analyzed under the focus of a Normal Forest, the figures for average volume of wood available for supply showed in the last row of Table 6-2 are closer to the figures under column corresponding to period 2031-2038 for S4 and S5. Hence no additional expansion is projected for the period of 2039-2047 for the mentioned scenarios.

The above analysis factors in the different expansion rates for each scenario, given that they have to be completed by a specific year, as shown in Figure 6-4. For S3, the expansion starts in 2018 with an initial establishment of 4,335 ha, and gradually increases over 17 years at an average rate of 2,450 ha/year, translating into an establishment of 45,884 ha in 2035, when the target area of 0.765Mha is reached. For S4, the annual planting rate is approximately 10 times that of S3, in order for the total area under S4 to reach 1.5 Mha by 2025, as indicated in the PFCm policy. Finally, for S5, the plantation rate between 2021 and 2025 is even higher than that of S4, since the objective of S5 is to reach a commercial forest plantation area of 2 Mha by 2025. As shown in the same figure, the annual planting rate up to 2020 is the same for both S4 and S5, due to the necessary time it takes for changes of such magnitude to be implemented.

Note that, as Figure 6-5 illustrates, the projected volumes for all scenarios during the period 2016-2022 are pretty close, which makes comparison of no additional importance to the discussion[64].

6.6.1.3 Harvests without replacement (Scenario 6)

If the initial area of commercial forest plantations for wood production in Colombia (0.3 Mha) were to be harvested without replacement (S6), and using a harvest rate of area equivalent to 3 Mm^3rsc/ year as per (Held et al., 2017), the initial area would only provide wood for the years up to 2038, and perhaps a few months in 2039, for the operation at full capacity of the current industries of pulp, wood-based panels, and sawnwood. After 2039, the total and average volumes available would be zero.

6.6.2 Viability of alternative forest policy goals and their impact on the forest markets

The above results seem to indicate that no scenario that promotes the diminishing of the initial area of commercial forest plantations for wood production in Colombia is a viable one. Decreasing the initial area by any degree, or bringing it to zero, would put under risk the existence of the Colombian commercial forest plantation for wood production value chain (PFCm value chain), an important value chain with more than six and half decades of generating multiple societal benefits, including, according to (MADR, 2017a), 40,000 jobs directly related to establishing, managing and harvesting forest plantations.

Simulation results also point out that scenarios with zero increase of the 2015 initial area (0.3 Mha and 0.45 Mha), but with uninterrupted maintenance of existing area under sustained rotation, are also not viable. Under these scenarios, the 4.1 Mm^3rsc/year and 5.7 Mm^3rsc/year of wood availability, respectively, during 2015 to 2047, on average, would be insufficient for supplying the unprocessed wood market, and for the expansion of the country's manufactured wood primary

[64] Actually, table 6-3 shows a peak of production in period 2039-2047. However, when analyzed under the focus of a Normal Forest, the figures for average volume of wood available for supply showed in the last row of table 6-2 are closer to the figures under column corresponding to period 2031-2038 for S4 and S5. Hence no additional expansion is assumed for period 2039-2047 for the mentioned scenarios.

products industry. The already-delayed industry expansion is much needed to meet the increasing demand for manufactured wood primary products in Colombia (pulp, panels and sawnwood). This demand was estimated to be around 5.5 Mm^3rsc of equivalent wood in 2013, with a shortfall in domestic supply of 1.8 Mm^3rsc of wood equivalent, which was covered by imports (Held et al., 2017). It should be pointed out that almost the entire demand for primary products is for national consumption; in 2013 Colombia exported only 3% of the mentioned demanded volume (Held et al., 2017). It is also estimated that 7.3 Mm^3rsc of equivalent wood for manufactured wood primary products will be demanded annually in Colombia by 2022, and this demand will increase to 9.2 Mm^3rsc of equivalent wood per year by 2030, and up to 10.6 Mm^3rsc of equivalent wood per year by 2038 (these estimations do not include an increase in exports nor the potential domestic demand generated by the implementation of the PFCm policy) (Martinez-Cortes et al., 2018b)[65].

It seems that a decision of not increasing the initial area of commercial forest plantations for wood production in Colombia, an economic activity for which the country has comparative advantages (Norton et al., 2008), would result in maintaining the negative trade balance of Colombia´s wood forest products. This balance has been negative for a long time, due to the continuous imports of pulp, paper and paperboard, but it has exacerbated in the last two decades due to substantial increases in imports of products for the pulp and paper industry, wood-based panel industry and sawnwood industry. By 1996, Colombia was already reporting a negative trade balance of about 325 million of American dollars (MUSD); this figure came from 391 MUSD in imports and 66 MUSD in exports, which included the following product net balances: roundwood (+0.2 MUSD), wood furniture (-6.9 MUSD), sawnwood (-1.5 MUSD), wood-based panels (-13.0 MUSD), and pulp, paper and paperboard (-303.5 MUSD) (Martinez-Cortes, 1998). Based on data from Held et al. (2017), in 2014, this trade balance reached -1,044 MUSD (1,044.6 MUSD in imports and 0.6 MUSD in exports, with the trade balance being negative for all products in both monetary and physical terms). If the trade balance is observed in physical units (volume), it can be noted that, during the last two decades, Colombia has had a negative trade balance in volume (i.e., volume of

[65] Demand figures are preliminary and were estimated by using an analysis similar to a “gap model” during the redesigning of Colombia’s forest plantation policy in 2016 and 2017.

wood forest products imported greater than volume of wood forest products exported) and that this deficit has increased substantially in all wood forest products but specially for panels as well as pulp, paper, and paperboard products.

The results indicate that scenarios of increasing the 2015 initial area to 0.765 Mha, 1.5 Mha and 2 Mha, and keeping these target areas under sustainable rotation, are viable options. Under these scenarios, once the total mass of forest plantations has reached, on average, the level of a "normal forest", the projected amounts, respectively, of 14 Mm^3rsc/year, 26 Mm^3rsc/year, and 35 Mm^3rsc/year of wood available would allow for the supplying of the unprocessed wood market with national wood, the expansion of the manufactured wood primary products industry, meeting future national demand for these primary products, as well as the development of the domestic and exports markets for the manufactured wood products in general. An expansion of manufactured wood primary products industry usually allows the flourishing of the manufactured wood secondary products industry (also known as the major value-added wood products industry); i.e., an industry whose output is products such as: paper, and paperboard and packaging, laminated wood, wood furniture, among others. It is also expected that enough raw material (wood) would influence the development of innovative manufactured wood products industry such as: forest bioenergy products, chemical, food and cosmetic wood products, and bio composites industries. The difference between the first expansion scenario (S3) and the last two (S4 & S5) lies in the available time and the magnitude of these endeavours.

Under the 0.765 Mha target (S3) scenario, projected to be reached by 2035, the manufactured wood primary products industry would have enough raw material from the unprocessed wood market to conduct its first expansion as early as in the period between 2023 to 2030, when 5.4 Mm^3rsc/year of wood is available. However, this expansion would be insufficient to meet the domestic demand for its products during that period (i.e 7.3 Mm^3rsc of equivalent wood/year). Only during 2031-2038 would the unprocessed wood market have a sufficient amount of raw material (9.1 Mm^3rsc/year), that would allow for the expansion of said industry to such a size that would make it capable of completely meeting the demand of the Colombian market for pulp, boards, and sawnwood (i.e., 9.2 Mm^3rsc of equivalent wood per year). This implies that, up to

2030, Colombia would continue to increase its imports, and that, up to 2038, all imports and national production of the manufactured wood primary products industry would be exclusively dedicated to meeting the domestic consumption needs[66]. Only during the 2039-2047 period, when the production in the commercial forest plantations for supplying the unprocessed wood market would reach 14 Mm^3rsc/year (under a normal forest focus), would the manufactured wood primary products industry be able to expand to the point where it would be able to both meet the total demand of 10.6 Mm^3rsc of equivalent wood per year (mostly domestic consumption), and marginally develop the exports markets for the same products.

Under the 1.5 Mha scenario (S4) (the policy goal of the National Forest Development Plan of Colombia and the PFCm policy to be achieved by Dec 2025), the final industrial expansion size would be 12 Mm^3rsc/year, more than that under the 0.765 Mha scenario. Furthermore, what happens in this latter scenario for the forest markets between 2039 and 2047 could happen 15 years sooner under the 1.5 Mha one. For the 2023-2030 period, and then during the 2031-2038 period, the unprocessed wood market could be supplied with 15 Mm^3rsc/year and 26 Mm^3rsc/year, respectively; these amounts would allow for the expansion of the manufactured wood primary products industry to entirely meet the domestic consumption during such periods (i.e 7.3 Mm^3rsc and 9.1 Mm^3rsc of wood equivalent/year). Starting in 2023-2030, Colombia would have an excess of raw material for additional expansions of the manufactured wood primary products industry, to account for an expected additional demand to be generated due to the implementation of the PFCm policy. This additional demand is expected to be generated especially by fulfilling policy goals related to the development of an innovative manufactured wood forest products industry in Colombia (e.g. forest bioenergy, which in 2017 was in its infancy), an increase of per-capita national consumption of wood and its manufactured products (whose figures of 12 m^3/per capita for 2015 are deemed to be pretty low (Martinez-Cortes et al., 2018b)), the recovery of some wood forest products market segments that the manufactured wood products industry has lost in the

[66] Recall that demand figures were estimated under the assumption of a no growth of exports, and in 2013, the base year for the demand estimation, Colombia exported negligible quantities of wood forest products.

country's economy (such as those in the construction sector), and the development of the export markets for Colombian wood forest products.

For the 2.0 Mha scenario (S5), the quantity of 35 Mm^3rsc/year of wood available for harvesting once the total mass of forest plantations is considered a "Normal Forest", represents an additional 9 Mm^3rsc/year potential expansion of the Colombian manufactured wood primary products industry as compared to S4. The annual volume harvested under S5 is comparable in order of magnitude to the annual harvest of Chile, which, with an area of 2.4 Mha of forest plantations under sustained rotation, harvested 43.6 Mm^3rsc in 2015 (Gisling et al., 2017).

In terms of the cost, the average cost of per hectare (establishment and management for the first four years without including the cost of land) is USD1,420 (2017). Hence, the total costs of S3, S4, and S5 scenarios will be 0.66, 1.7, and 2.4 billion USD (2017), respectively. The socio-economic benefits of these scenarios, in terms of expansion of forest industry to meet domestic demand, employment potential, increased export, and contributions to trade balance, are already discussed earlier. A deeper economic analysis, which is beyond the scope of this paper, will provide a comprehensive picture of economic ranking of these scenarios, and should be the subject of future research.

6.7 Final thoughts: SCRPFC & the Colombian Forest Sector Model (CFSM)

The apparent usefulness of the SCRPFC in analysing and evaluating policy goals was demonstrated in the preceding sections. Information related to the available volumes for supply provides key elements in understanding the interactions among some variables affecting the supply and demand of wood forest products in Colombia: the extension of the forest plantations, the supplying of wood to the unprocessed wood market, the current and potential size of the manufactured wood products industry, and the supplying of the markets of manufactured wood products. However, the interactions among the above-mentioned variables are far more complex than that discussed in the preceding sections.

These variables are not working in isolation, but they are affected by other groups of variables from other parts of the forest sector, such as: the wood available for supply from natural forests, agroforestry systems and trees outside the forests; the behaviour of the economic agents in the unprocessed wood market, which is influenced by what happens in the manufactured wood products market; and by the behaviour and actions of economic agents within each market, which are in turn influenced by the performance of the Colombian and the global economies, to name a few.

As such, the simulations presented in this paper are the first input needed to estimate a more complete and powerful benchmark, useful in conducting the analysis of the PFCm policy: the wood forest product markets behavior. The design of the SCRPFC and the volume estimation exercises are part of the CFSM, a sectoral model developed by Martinez-Cortes (2022) as part of his doctoral thesis research, in order to estimate the supply and demand for wood forest products in the Colombian context, and estimate the potentially achievable quantities and prices of wood forest products for the years that follow.

These and other more complex interactions that happen within and outside of the forest sector limits are what is simplified into core relations within the CFSM. The forecasts generated by the CFSM would provide benchmarks on the required quantities of wood traded in the unprocessed wood market (a part of which would come from the wood available for supply from Colombian commercial forest plantations), and the prices at which the trades would happen, as well as the quantities of manufactured wood products that economic agents would trade in the market for these products together with the agreed upon price. The CFSM analyses that addresses the question that how the expected *quantities and prices* for wood and manufactured wood products in the following years synthetize the *expected behaviour of the (wood) forest markets in the long run*, will be presented in the future publications [in the following chapter in this thesis document]. The findings of these publications [chapter 7] will provide a better benchmark for feedback and recommendations on the viability of alternative policy goals, such as: the extension of Colombia's forest plantation area, the final size of the manufactured wood products industry, and the development of the country's unprocessed wood market as wells as the manufactured wood products one.

Chapter 7
Impacts estimation of the 2018 – 2038 Commercial Forest Plantation Value Chain Policy using the CFSM-I

7.1 Introduction

This chapter is devoted to demonstrating how the complete CFSM-I is an effective tool for a more comprehensive sectoral analysis by using it to simulate policy experiments. As such, it is complementary to chapter 6, in which the Colombian forest plantation simulator (named SCRPFC) was presented, and its usefulness was established for analyzing the long-term future of the Colombian forest sector in physical terms[67].

The chapter fulfills the aim of the second and fourth specific objectives of the research, partially accomplished in chapter 6, and presents a full development of the third research specific objective. For the second objective, this chapter examines the impacts on supply and demand of Colombia's wood forest products market coming from the development of new commercial forest plantations for wood production (PFCm) reaching 1.5 million hectares- Mha (Colombian Forest Development National Plan-FDNP's goal). For the fourth objective, it discusses these impacts to those of the other five alternative FDNP goal scenarios presented in chapter 6: 0.3 Mha, 0.45 Mha, 0.765 Mha and 2.0 Mha under sustainable rotation, and 0.3 Mha harvested without replanting. Regarding the

[67] The CFSM-I was built without any constraints to be used for running several types of experiments. For example, in section 5.5 the model was used to run a counterfactual-type experiment to find the equilibrium prices and quantities for the market clearing situation, to validate the CFSM-I. In this chapter, the CFSM-I is used to run the forecasting-type experiments. "Forecasting involves a simulation of the model forward in time beyond the period of estimation" (Pindyck & Rubinfeld 1998). As explained by these authors, there are two types of forecasts: *ex post forecast* and *ex ante forecast*; the former ranges from the end of the estimation period to the "present", while the latter goes from the "present" to the future. It is important to keep in mind that the term "present" is a matter of most current data availability. This was demonstrated in this research as follows. In the middle of 2021, when the CFSM-I was run to produce an *ex post forecast* to test its forecasting accuracy (see section 5.5.2), the most current actual data was only up to 2018, hence "present" was 2018. In this chapter, when the model was run in October 2022 for producing an *ex-ante forecast* (2021-2047), the most current data was 2020, hence the "present" was 2020. As for the policy experiment related to the changes in capacity production of the manufactured wood forest industry, explained in this chapter, the CFSM-I is simulated for several setups of the Colombian forest plantations area, it can be considered that the model is used to produce output useful for scenario analysis.

third objective, this chapter considers the impact that an expected increase in the number of manufacturing plants (a positive shock on the supply of manufactured wood forest products) would have on the performance of two important macroeconomic factors: domestic consumption and imports.

The empirical exercise for attaining the above goals is described in the next section of this chapter, followed by the results and completed by discussion of them, in a separate section. Conclusions and recommendations for policy makers derived from this chapter have been moved to chapter 8, which concludes this research.

7.2 Empirical Exercise for Policy experiments

The empirical exercise comprised simulating the CFSM-I over the period 2021-2047 for several scenarios, grouped into the Categories I and II of policy experiments. The former cluster includes six simulations for completing the second and fourth specific objectives of the research, while the latter comprises the simulations for achieving the third research specific objective. Under Category I, the CFSM-I is simulated for the scenarios S1 to S6 explained in chapter 6 (Table 6-1 and Figure 6-4). By simulating the CFSM-I under S1 to S6, the shock is applied to the VAST variable of the equation of supply of the unprocessed wood for the manufactured wood products industry and final use other than firewood sourced in forest plantations (S^{MWfprw}). For category II, the CFSM-I is simulated for the same scenarios (except S6), by introducing shocks on the capital (K) and labor (L) variables of the equations of supply of the manufactured wood products of the wood, furniture, and pulp & paper industries[68].

[68] For the policy experiments the CFSM-I is simulated without including the market for the unprocessed wood for firewood FWrw.

7.2.1 Simulation of CFSM-I for Category I of policy experiments

For simulating the CFSM-I by shocking the standing volume of wood for supply at beginning of the year in the PFCm, named VAST, the following was considered[69].

7.2.1.1 2021-2047 VAST computations

In the CFSM-I, the VAST is an exogenous variable of the equations for Supply and Imports of the unprocessed wood market (sub)model named UMW. By defining an area expansion scenario for Colombia's PFCm, and the duration of its implementation, the policy maker or modeler is establishing the direction and magnitude of the shock. By using the SCRPFC, this area expansion scenario is translated into annual expected volumes of wood available for supply from forest plantations, named VAS[70]. Then, by means of the identities that connect the SCRPFC and the UWM, and using both the expected annual VAS and equilibrium harvested volumes from PFCm ($VH^{MWfprw*}$), recursively, it is possible to estimate the annual VAST for the beginning of each of the years of the period simulated.

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[69] $VAST_t$ of commercial forest plantations represents the actual standing volume of wood in the CFPm complying, at least, with the minimum standards of the market in Colombia; volume that remained in the CFPm at the end of year t-1 (or the beginning of year t) after the annual harvest (VH_{t-1}), ready to be harvested during year t. The identities to estimate the VAST are numbered 44 and 45 (see Table 3-4). Table 3-4 also shows Equation 41, which is the behavioral estimated equation for the supply of unprocessed wood for the wood products industry and final uses other than firewood from forest plantations (S^{MWfprw}). VAST is an exogenous variable of equation 41, with positive estimated coefficient, and of equation 52 with negative estimated coefficient. In the CFSM-I, unprocessed wood for firewood (FWrw) is not included as a product of the commercial forest plantations, hence $VAST_t = VAST_t^{MWfprw}$. Recall that MWrw is the unprocessed wood for the manufactured wood products industry and final use other than firewood, MWfprw is the unprocessed wood for the manufactured wood products industry and final use other than firewood sourced from the forest plantations, and MWnfrw is the unprocessed wood for the manufactured wood products industry and final use other than firewood sourced from the natural forest.

[70] This procedure was the subject of chapter 6. VAS is the usable wood in the commercial forest plantation for wood production (PFCm) at the end of each year, as predicted by the SCRPFC. It corresponds to the wood that would be obtained from plantations by carrying out the thinnings and final harvest scheduled in accordance with the plantation management theoretical model (aka silvicultural theoretical regime) and that complies, at least, with the minimum standards of the market of unprocessed wood in Colombia. Note that the denomination of VAS and VAST can be applied to different sources of wood: forest plantations, natural forest, agroforestry systems, trees outside forest. However, as explained before in the CFSM-I, VAS and VAST are variables pertaining to the forest plantations. Hence, in this chapter, VAS and VAST refer only to this source of wood.

For any year of the simulated period, $VH^{MWfprw}*$ is the result obtained from $VH^{MWrw}*$ minus the volume of MWrw sourced in the Colombian natural forest ($VH^{MWnfrw*}$)[71]. $VH^{MWrw}*$ results of dividing the Supply ($S^{MWrw}*$) by the Price of Supply ($PS^{MWrw}*$). $S^{MWrw}*$ is the sum of $S^{MWnfrw}*$ plus $S^{MWfprw}*$. Both S* and $PS^{MWrw}*$ are obtained from the clearing condition of the market of MWrw, i.e., the market of unprocessed wood for the manufactured wood products industry and final use other than firewood. As the $PS^{MWrw}*$ in the CFSM-I is expressed as a deflator, before applying the division operation, $PS^{MWrw}*$ must be converted into a real level price, by multiplying it with the 2015-real level price, as the CFSM-I is expressed in 2015-constant prices.

The annual values of VAS for S1 to S6 were discussed in chapter 6. They were summarized in Figure 6-5. A summary of VAS for selected years and the total VAS for the period of simulation are presented in Table 7-1. The VAS for each year and scenario can be seen in Appendix 7-1.

Table 7-1 Annual VAS for six scenarios of area expansion of Colombian forest plantations for 2014-2047 for selected years (m^3rsc at the end of each year)

Year	Availability of wood from thinnings and final harvest					
	S1 PROFOR2015	S2 MADR2015	S3 PROFOR2035	S4 PNDF/PAPFCm1	S5 PNDF/PAPFCm2	S6 PROFOR2015-SR
2015	2 914 093	3 792 346	2 914 093	2 914 093	2 914 093	2 914 093
2020	2 427 944	3 072 161	2 427 944	2 900 788	2 900 788	2 242 758
2022	3 160 029	4 168 283	3 316 716	4 962 162	4 962 162	2 880 870
2025	4 168 021	6 481 942	4 700 540	11 106 318	12 802 369	3 105 699
2030	3 213 741	4 590 116	5 969 755	21 403 287	28 743 749	850 611
2035	3 112 170	7 406 753	8 481 826	23 340 201	30 895 415	-
2038	2 315 775	3 560 488	11 032 602	18 688 280	21 864 625	-
2040	4 114 858	4 969 425	13 980 707	30 898 646	43 807 330	-
2045	5 672 374	8 566 525	13 840 471	22 661 162	29 362 974	-
2047	6 491 961	9 637 260	17 077 139	26 756 521	34 995 484	-
Total	155 070 918	210 603 434	303 205 600	665 321 272	867 810 514	71 486 276

2022, 2030 and 2038 are ending years of the PFCm policy periods of implementation.

[71] $VH^{MWnfrw*}$ is determined by the division of the $S^{MWnfrw}*$ by $PS^{Mwrw}*$. It is important to note that, in the CFSM-I, $S^{MWnfrw}*$ does not depend on the VAST in the natural forest.

7.2.1.2 2021-2047 Values of CFSM-I's Exogenous Variables other than VAST

In addition to the annual values of VAST, to simulate the CFSM-I for the period 2021-2047 under market clearing, annual values of all the other exogenous variables of the model were needed. Those values are summarized in Table 7-2 at the five-year level. This table also includes values for some key years and the last year of the period of simulation. Units, and sources for the variables of Table 7-2 are presented in the same table[72].

Future values exchange rate (RX), population (N), rural population (NR) and number of households (NHH) were sourced from the Organization for Economic Cooperation and Development (OECD) long-term economic outlook and DANE, which have annual estimates up to 2060 and 2070. Future values of Income (Y) and consumer price index (PC) were proxied by using the OECD estimates for GDP and its deflator, respectively. The 2023-2027 estimates for unemployment (U) were sourced from the medium-term economic outlook of the International Monetary Fund (IMF), values of this variable for the 2028 – 2047 period were assumed to be the same as it was forecasted by the IMF for 2027.

For the rest of the variables of Table 7-2 no future values of any source were available. Hence, those values were estimated through the period of simulation, starting from the following year for which the last actual value was registered. Correlations between the Price deflator of housing (P^h) and of housing construction materials (P^{hcm}) with the GDP Price deflator, respectively, served as a mean for the estimations of P^h and P^{hcm} given that actual data for this variables are highly correlated with actual data for the GDP deflator (r = 0.98 and r = 0.99, respectively). Also, correlations between the US-GDP index and the US Industrial production index (IPI), and the US-GDP deflator and the US forest industries (WEPI), were used for estimating the 2022-2047 values of IPI and WEPI, for which correlations with the corresponding variables were high: $r_{\text{US-GDP index, IPI}} = 0.97$, $r_{\text{US-GDP deflator, WEPI}^w} = 0.97$, $r_{\text{US-GDP deflator, WEPI}^f} = 0.99$, $r_{\text{US-GDP deflator, WEPI}^f} = 0.99$.

[72] The sources of all variables of the CFSM-I for the period 1970-2020 (2021 or 2022 for some of them) were presented in table 5-4 of chapter 5.

Table 7-2 Annual values of the CFSM-I exogenous variables used for running the policy experiments

CFSM-I variable Acronym	Complete Identification and Units for series in the CFSM-I	Source for actual data	Source of data after the last year of actual data	Last year for actual data (On oct 2022)	2015	2019	2020	2022	2025	2030	2035	2038	2040	2045	2047
CURw	CURtw - Capacity utilization rate for Colombia´s wood industry (percentage)	Thoumi (1971) Study for National Department of Planning, Coyuntura Economica Journal (1972-1990) based on Fedesarrollo's Industrial Survey and Enterprise Opinion Survey (industrial Sector), and Fedesarrollo's Capacity utilization rate database (1991-2019) based on Fedesarrollo's Entrerprise Opinion Survey	Same level of last year actual data	2022	80	77	78	80	80	80	80	80	80	80	80
CURz	CURtz - Capacity utilization rate for Colombia´s pulp & paper industry (percentage)	Thoumi (1971) Study for National Department of Planning, Coyuntura Economica Journal (1972-1990) based on Fedesarrollo's Industrial Survey and Enterprise Opinion Survey (industrial Sector), and Fedesarrollo's Capacity utilization rate database (1991-2019) based on Fedesarrollo's Entrerprise Opinion Survey	Similar level of last year actual data	2022	77	74	74	82	80	80	80	80	80	80	80
HCSt	HCSt - Housing construction starts (Thousand of square meters approved for construction)	DANE, Construction licenses, 1970 - 2019	Estimation based on DANE's projections of Colombia's dwellings 2018-2050	2021	18 845	18 214	13 385	16 986	17 559	17 404	16 237	15 705	15 425	14 728	14 485
IPI	IPIt - US Industrial Production Index (unitless, 2015 =1)	Federal Reserve Bank of St. Louis	Estimation based on the historical correlation between IPI and US GDP index applied to 2022- 2060 US GDP index from OECD database	2021	1.00	1.02	0.94	1.14	1.20	1.30	1.40	1.46	1.50	1.61	1.65
Kf	Ktf - Capital of the furniture industry (Value of machinery and equipment + building and structures in the annual manufacturing survey. 2015 Thousand million COP)	DANE, Manufacturing Annual Survey	Same level of last year actual data	2020	722	1 509	1 508	1 508	1 508	1 508	1 508	1 508	1 508	1 508	1 508
Ktz	Ktz-Capital of the pulp & paper industry (Value of machinery and equipment + building and structures in the annual manufacturing survey. 2015 Thousand million COP)	DANE, Manufacturing Annual Survey	Same level of last year actual data	2020	3 417	5 269	5 605	5 605	5 605	5 605	5 605	5 605	5 605	5 605	5 605
Lf	Ltf - Labor of the furniture industry (Number of employees in the annual manufacturing survey)	DANE, Manufacturing Annual Survey	Same level of last year actual data	2020	22 847	17 098	14 451	14 451	14 451	14 451	14 451	14 451	14 451	14 451	14 451
Ltw	Ltw - Labor of the wood industry (Number of employees in the annual manufacturing survey)	DANE, Manufacturing Annual Survey	Same level of last year actual data	2020	6 931	5 015	4 750	4 750	4 750	4 750	4 750	4 750	4 750	4 750	4 750
Ltz	Ltz-Labor of the pulp & paper industry (Number of employees in the annual manufacturing survey)	DANE, Manufacturing Annual Survey	Same level of last year actual data	2020	17 278	18 054	18 085	18 085	18 085	18 085	18 085	18 085	18 085	18 085	18 085
NHHt	NHHt - Households (Thousand people)	DANE, Colombia's Household Survey (1970 - 1978), and Colombia's Households 1985-2005 Estimations and 2006-2020 Projections, 1979 - 1984 Estimations based on population by the author of this research	2018-2050 Projections of Colombia's population, dwelling, and households based on Population Census of 2018 from DANE	2020	13 585	14 718	15 000	17 353	18 777	21 189	23 463	24 756	25 597	27 632	28 420
NRt	NRt - Rural Population (Thousand people)	World Bank, World Development Indicators	Estimation for Colombia's rural population - World Urbanization Prospects from United Nations (2021-2050)	2021	9 616	9 512	9 451	9 140	8 844	8 330	7 796	7 463	7 238	6 670	6 442
Nt	Nt - Total population (Thousand people)	World Bank, World Development Indicators	2021-2070 Projection for Colombia's population from DANE	2021	47 521	50 339	50 883	51 609	53 217	55 678	57 804	58 906	59 564	60 955	61 412
PC	PCt - Consumer price index (Unitless, 2015 = 1)	Colombia's Central Bank - Consumer's price index. Estimated base on CPI 2018-base (Dec 2018=100)	Proxied by using 2022-2060 Colombia GDP deflator from OECD Database	2021	100.00	117.89	119.80	133.65	146.48	167.81	193.07	210.22	222.57	256.99	272.30
Pth	Pth - Price deflator of housing (Used housing price index. Unitless, 2015 = 1)	Central Bank of Colombia; Used Housing Price Index (IPVU)_Base 1990 = 100. 1.1.1. Nominal and real index - Total, by city, VIS and non VIS_annual periodicity and real estate prices in the housing market in Bogota 1970-2004 Samuel Jaramillo González (2004). CEDE Document 2004-42 ISSN 1657-7191 (Electronic Edition) October, 2004. https://www.academia.edu/7380909/Precios_inmobiliarios_de_vivienda_en_Bogot%C3%A1_1970-2013	Estimation based on the historical correlation between Price deflator of housing (P^h) with Colombia's GDP Price deflator, applied to 2022-2060 Colombia's GDP Price deflator from OECD Database	2021	1.00	1.14	1.14	1.32	1.44	1.65	1.90	2.07	2.19	2.53	2.68
Pthcm	Pthcm - Price deflator of housing construction materials (Unitless, 2015 = 1)	Central Bank of Colombia; Used Housing Price Index (IPVU)_Base 1990 = 100. 1.1.1. Nominal and real index - Total, by city, VIS and non VIS_annual periodicity and real estate prices in the housing market in Bogota 1970-2004 Samuel Jaramillo González (2004). CEDE Document 2004-42 ISSN 1657-7191 (Electronic Edition) October, 2004. https://www.academia.edu/7380909/Precios_inmobiliarios_de_vivienda_en_Bogot%C3%A1_1970-2013	Estimation based on the historical correlation Price deflator of housing construction materials (P^{hcm}) with Colombia's GDP Price deflator, applied to 2022-2060 Colombia's GDP Price deflator from OECD	2021	100.00	104.29	108.09	133.06	145.83	167.07	192.22	209.29	221.59	255.85	271.09
RX1	RX1 - Exchange rate (COP/USD)	Federal Reserve Bank of St. Louis	2022-2060 Colombia's Exchange Rate projections (USD/COP) from OECD Database	2021	2 742	3 281	3 695	3 859	3 532	3 231	3 066	3 009	2 985	2 964	2 968
Ut	Ut - Unemployment (percentage)	DANE, DANE's Statistical Yearbook (1970-1975), DANE's historical time series 1976 -1983, 1984-2000, DANE Household Survey 2001-2017 and DANE's Website 2018	2022-2027 Estimation of Unemployment for Colombia from International Monetary Fund (IMF). For 2028-2047, the 2027-rate projected by by the IMF.	2021	8.9	10.9	16.7	11.3	10.0	9.9	9.9	9.9	9.9	9.9	9.9
WEPItf	WEPItf - US Producer Price Index by Commodity for Furniture and Household Durables: Household Furniture (unitless, 2015 =1)	Federal Reserve Bank of St. Louis	Estimation based on historical correlation US-GDP deflator and US Producer Price Index by Commodity for Furniture and Household Durables: Household Furniture, applied to 2022-2060 US GDP Price deflator from OECD Database	2021	1.00	1.08	1.09	1.14	1.22	1.35	1.50	1.59	1.66	1.83	1.90
WEPItw	WEPItw - US producer price index by commodity for lumber and wood products (unitless, 2015 =1)	Federal Reserve Bank of St. Louis	Estimation based on historical correlation US-GDP deflator and US producer price index by commodity for lumber and wood products, applied to 2022-2060 US GDP Price deflator from OECD Database	2021	1.00	1.07	1.15	1.11	1.19	1.32	1.46	1.55	1.61	1.78	1.85
WEPItz	WEPItz - US Producer Price Index by Commodity for Pulp, Paper, and Allied Products (unitless, 2015 =1)	Federal Reserve Bank of St. Louis	Estimation based on historical correlation US Producer Price Index by Commodity for Pulp, Paper, and Allied Products, applied to 2022-2060 US GDP Price deflator from OECD Database	2021	1.00	1.04	1.04	1.14	1.22	1.35	1.50	1.59	1.65	1.83	1.90
Yt	Yt - Income (2015 Thousand million COP)	World Bank, World Development Indicators	Proxied by 2022-2060 Colombia GDP projections from OECD Database	2021	809 368	906 566	855 801	984 074	1 079 496	1 226 613	1 354 328	1 421 661	1 463 288	1 558 497	1 593 573

For the same period, the future values of the housing construction starts (HCS), which is measured by the square meters approved for construction licenses, were estimated based on the DANE projections of the number of dwellings for 2018-2050 and the average of square meters of dwellings obtained from the construction licenses for dwellings between 1993 to 2022 (33.63 m^2). In addition, for the whole period of simulation, the manufactured wood forest industries capacity utilization rate (CUR) was assumed to be 80%, a value close to the utilization rate of those industries in the last decade. Finally, in estimating the 2021-2047 values of the exogenous variables labor (L) and (K), it was assumed that these future values will be the same as they were in 2019. This assumption implies that owners of capital in the wood forest products industries will invest, during 2021 to 2047, annually only the necessary monetary amounts to maintain the value of capital of these forest industries equal to that on December 31, 2019, i.e., no expansion of these industries will happen. This is so, to establish the base scenario (S1) for the set of simulations of Category II, where variables L and K are shocked, which are explained in subsection 7.2.2.

Additional explicative notes for the above estimations can be found in Appendix 7-1. This appendix includes the annual values for all exogenous and endogenous variables of the CFSM-I for the period 1970- 2047. It also includes the 1970-2022 (average) level prices for the unprocessed wood for the manufactured wood products industry and final use other than firewood (MWrw), the unprocessed wood for firewood (FWrw) and other prices that were derived in this research by using the monetary and physical quantities data of the 2015-base Colombia's Forest Environmental and Economic Account of the Satellite Accounts of DANE (DANE 2022a, 2022b), among others. The 2010-2022 level prices for some products in the Colombian wood forest products markets are summarized in Table 7-3. These level prices are key to establishing the bounds for the forecasting of deflators in the CFSM-I and for the deflators forecasted.

Table 7-3 Prices for wood forest products in Colombia

Product	Mesurement unit	Colombia's national product at domestic market		Chile's product[0]				Notes
				Exports (FOB Chile)		Domestic market		
		USD	COP	USD	COP	USD	COP	
Forest-plantation pulpwood logs	m^3rsc	42	115 122			30	82 230	1
Forest-plantation saw logs	m^3rsc	75	205 575	97	265 877	50	137 050	1
Forest-plantation logs (average)	m^3rsc	65	178 439			44	120 604	1
Natural-Forest & forest-plantation logs	m^3rsc	141	385 805					
Chips	ton			69	187 759			
Sawnwood (planned)	m^3	320	876 746	272	745 552	141	386 860	2
Sawnwood clear								
Blanks (radiata pine)	m^3			516	1 414 356			
Boards (radiata pine)	m^3			492	1 348 572			
Mouldings (radiata pine)	ton			1 900	5 207 900			
wood-based panels MDP or MDF	m^3	503	1 380 012	793	2 173 599	525	1 437 828	3
MDF	m^3			889	2 436 998	499	1 368 195	3
MDP	m^3			756	2 072 881	380	1 400 726	3
Particleboard	m^3			542	1 484 357			
Hardboard	m^3			458	1 256 292			
Plywood (radiata pine)	m^3			1 335	3 659 235	1 193	3 270 293	3
wood pulp (include both bagasse pulp & wood pulp for Colombia)	ton	319	873 907	596	1 633 636	573	1 571 791	4
Newsprint	ton			618	1 693 938			
Paper and paper products	ton	912	2 499 720			2 622	7 187 443	4

[0]Freight to Colombia in 2015 were on average USD 50/m^3 of sawnwood or wood-based panels and USD 40/ton for wood pulp. [1]Domestic prices for both Colombia and Chile are at the factory entrance. [2]Domestic prices are quoted in the sawmills. [3]Chile's domestic prices (USD and COP) are per m^3 in Santiago. [4]For Chile, domestic prices were estimated based on the value of production at purchaser prices (i.e., basic prices + taxes + margins of commercialization and transportation) on the Supply and Use tables for products from Chile's national accounts for 2015, 2013-base in current prices (Banco Central de Chile, 2022) and production statistics from Gisling et al. (2016) and Alvarez et al (2022). For Colombia, the same calculation was done based on Colombia's National Accounts Supply and Use tables for 2015, 2015-base in current prices (DANE, 2022, 2022a, 2022b) and Andi (2016).

7.2.2 Simulation of CFSM-I for Category II of policy experiments

For simulating the CFSM-I for the category II of policy experiments, the starting point were the output scenarios resulting from the simulations of the Category I of policy experiments: the base scenario (S1) and four alternative scenarios (S2 to S5)[73]. For each of these scenarios, the CFSM-I was simulated, for the market clearing case, after shocking the policy variables Labor (L) and Capital (K) of the manufactured wood products (sub)model, named MWM. In the MWM, both L and K are exogenous variables of the estimated behavioral equations for Supply (S). Labor is part of the equations of supply of manufactured wood products of the wood industry w (S^w), supply of manufactured wood products of the pulp & paper industry z (S^z) ,and supply of manufactured wood products of the wood industry f (S^f). Capital is only part of the equations for S^f and S^z[74].

However, before running the CFSM-I, the shocks on L and K had to be defined. As in Category I, shocks are defined by the policy maker or the modeler. Similar to what happened in the definition of VAS, an extra effort was made to define the shocks on L and K variables as close as possible to the reality of Colombia and its 2018-2038 Commercial Forest Plantation for the Wood Production Value Chain policy (PFCm policy).

7.2.2.1 Magnitude and duration of shocks on Labor and Capital

The magnitude and duration of the shocks on L and K for the simulations of Category II policy experiments, which are presented later in this subsection, were defined based on the expected expansion of production capacity (EEPC) for the Colombian wood forest products industry as follows:

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[73] S6 was excluded as it is not a factual scenario in Colombia.

[74] The Supply equations for w, f and z, in the CFSM-I, are numbered 10, 11, and 12, respectively (see Tables 3-2 in chapter 3 or Table 5-5 in chapter 5).

1. Definition of the EEPC for the w, z, and f industries. In the PFCm policy, some outline of the EEPC for the Colombian industry of wood forest products was set for the three periods of implementation of this policy. The outline was based on the expected supply from forest plantations of the PFCm policy, and the demand of wood forest products in Colombia. These guidelines divided the EEPC in two: the one covering the Colombian manufactured wood primary products and the other the innovative manufactured wood forest products industries, as shown in Table 7-4. The manufactured wood primary products industry includes the wood pulp, wood-based panels and sawnwood industries. The innovative manufactured wood forest products industry is made up of the forest bioenergy, forest bio-composites, and chemical, cosmetic, fashion and food products derived from wood industries, among others.

Table 7-4 contains the EEPC only for the second and third periods of implementation of the PFCm policy, as the policy included no expansion for its first period of the implementation (2018-2022). Figures for period 2015-2022 include the current production capacity, estimated for 2017 for sawn wood industry, wood-based panels, and wood pulp industries (widely discussed in Chapter 6), and for 2020 and 2021, the wooden furniture and the forest bioenergy industry, respectively.

The PFCm policy included some guidelines for the forest bioenergy industry, but none for the wooden furniture industry. Figures of table 7-4 for the latter industry correspond to estimations carried out under this research based on the information on capacity utilization rate of the furniture industry (Fedesarrollo 2022), and on the intermediate consumption of logs, sawnwood and wood-based panels by economic activity branches (in physical units), from the Supply-Use balance and the Use tables of the Forest Environmental and Economic Account (DANE 2022a, 2022b).

As mentioned in Chapter 6, for 2017, Colombia's total installed production capacity of the pulp, wood-based panels, and sawnwood industries, was estimated at 4.8 million m^3 of underbark roundwood (Mm^3rsc/year), broken down to 1.0 Mm^3rsc/year for wood pulp, 0.8 Mm^3rsc/year for wood-based panels and 3.0 Mm^3rsc/year for sawnwood (Martinez-Cortes et al. 2018b). And that, out of this total production capacity, 1.8 Mm^3rsc/year corresponded to the CIPTPI, i.e., the group

Table 7-4 Expected expansion of production capacity (EEPC) for the Colombian manufactured wood (forest) products industry (Mm^3rsc consumed/year, unless otherwise stated)

Type of wood forest products industry	Group of each Type	Specific industries under the CFSM-I groups of industries	Installed capacity production		
			2015-2022*	**2023 - 2030**	**2031 - 2038**
Traditional manufactured wood primary products	Wood industry (w)	Sawnwood industry**	3.0	7.5	15.0
		Wood-based panels industry	0.8	4.0	5.0
		Others			
		Total w	**3.8**	**11.5**	**20.0**
	Pulp & paper industry (z)	Wood pulp industry	1.0	4.5	6.0
		Others			
		Total z	**1.0**	**4.5**	**6.0**
Traditional higher value-added wood forest products (secondary manufactured)	Furniture Industry (f)	Wooden furniture industry (in m^3 of sawnwood and wood-based panel)***	0.6	1.6	3.0
		Others			
		Total f	**0.6**	**1.6**	**3.0**
Innovative manufactured wood forest products	Forest bioenergy		0.05	1.0	3.0
	(Wooden) Bio-composites				
	Derivates from wood for the chemical, cosmetic, food, fashion and other industries				
	Total Innovative manufactured wood forest products		**0.05**	**1.00**	**3.0**
Total of Colombian manufactured wood primary products industry			**4.85**	**17.00**	**29.00**
Total CIPTPI (group of industries of pulp, wood-based panels (boards), and innovative manufactured wood forest products)			1.9	10.5	17.0
Total Forest bioenergy (in MW)			5 MW	100MW	250MW

Source: This research, based on PFCm Policy (Martinez-Cortes et al. 2018b). Blanks represent data not available. *Figures for the current production capacity for all industries were estimated for 2017, except those for the wooden furniture industry which was estimated for 2020 and the forest bioenergy industry estimated for 2021. ** It includes the capacity production needed to process around 1.0 million of cubic meters of wood that arrives to the sawnwood industry in the shape of blocks sourced in Colombia's natural forests. *** The installed capacity production for wooden furniture was estimated in this research based on the consumption of logs, sawnwood, and wood-based panels and the capacity utilization rate of the furniture industry for 2020), sourced from DANE (2022a, 2022b).

of industries of wood pulp, wood-based panels (boards), and innovative manufactured wood forest products [75]. It is also known, from the same chapter, that these figures for 2017 (displayed in the fourth column of Table 7-4) have been almost the same as those of the country's total installed production capacity for the listed industries for any of the years between 2015 to 2021 and until October of 2022, except for the forest bioenergy industry.

For this latter industry, a 4.5 MW plant for producing forest bioenergy (Refoenergy Bita) was inaugurated in November 2021 in the municipality of Puerto Carreño, Vichada Departamento of Colombia (Valorem 2022) [76]. However, even with this advance, by October 2022, Colombia's innovative manufactured wood products industries are still on their early stages of development.

As the CFSM-I does not consider the markets for the products of the specific industries (as shown in the third column of Table 7-4) but the aggregate markets of the products of the first three rows of column two (i.e., w, z, and f industries), for the simulations it was assumed that EECP of w, f and z were only equal to EEPC of their individual specific industries. Forest bioenergy industry was excluded as no equations are considered in the CFSM-I.

Another way of noticing the EEPCs presented in Table 7-4 is by their factors. Except for the furniture industry, this measure of the expected expansion of the Colombian forest industry production capacity was widely used and discussed in Chapter 6. However, as some readers might

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[75] CIPTPI stands for the Spanish acronym "Conjunto de industrias de pulpa de madera, tableros de madera, y productos innovadores de madera" (Group of industries of wood pulp, wood-based panels, and innovative manufactured wood products). The industries grouped under CIPTPI have the characteristic that the unprocessed wood used as raw material in their production process has similar quality and it is, usually, wood of lower quality harvested in a commercial forest plantation.

[76] Refoenergy Bita is a Power Generation Plant, serving the municipality of Puerto Carreño, the capital city of Vichada Departamento in Colombia. According to Valorem (2022), Refoenergy Bita is the first 100% renewable and sustainable biomass energy project in Colombia to supply electricity to around 18,000 inhabitants of Puerto Carreño. The same source reports that the plant investment reached USD26 million and it is expected to capture 50,000 tonnes of CO_2 per year. For supplying the feedstock needed for its operation 1,200 ha of Eucalyptus are planted a year and completely harvested every three years (i.e., rotation is 3 years); the plant has a net generation capacity of 4.5 MW and for 2022, it will generate 32 million of Kw consuming 32,000 tons of wood biomass, the energy is distributed by ElectroVichada, an enterprise with 9,200 users in Vichada (Valora Analitik 2022). Valorem Group (a holding acting in Colombia) "is structuring a new project to generate energy through a 25 MW biomass plant in Villanueva, Casanare" Departamento of Colombia (Valora Analitik 2022).

find the factors more useful, and for easy comparison of the furniture industry EPCC with the other industries included in that chapter, the factors for the three industries modelled under the CFSM-I are summarized in Table 7-5.

Table 7-5 Expansion factor of the current Colombian manufactured wood (forest) product industry capacity production

Type of wood forest products industry	Group of each Type	Specific industries under the CFSM-I groups of industries	Expansion factor of the current capacity production		
			2015-2022**	2023 - 2030	2031 - 2038
Traditional manufactured wood primary products	Wood industry (w)	Sawnwood industry	1.0	2.5	5.0
		Wood-based panels industry	1.0	5.0	6.3
		Others			
		Total w	**1.0**	**3.0**	**5.3**
	Pulp & paper industry (z)	Wood pulp industry	1.0	4.5	6.0
		Others			
		Total z	**1.0**	**4.5**	**6.0**
Traditional higher value-added wood forest products (secondary manufactured)	Furniture Industry (f)*	Wooden furniture industry	1.0	2.6	4.9
		Others			
		Total f	**1.0**	**2.6**	**4.9**
Total manufactured wood (forest) products industry			**1.0**	**3.5**	**6.0**

2. Estimation of number of plants and size of investment for attaining the EECP in the Colombian wood, pulp & paper, and furniture industries, and expected employment. The next step for specifying the shocks on Labor and Capital variables was to estimate the number of plants and the size of investments for these industries, based on the estimation of EECP of Table 7-4 and 7-5.

Recent investments in the wood forest products industry in Colombia (e.g. RTA Colombia for wooden furniture) and Brazil (L.D. Celulosa for wood pulp industry) and business plans for plants of wood-based panels and sawnwood structured in the Forest Economy Study in the Framework of the Green Growth Taskforce for Colombia were used as the base for setting a “typical plant” for each of the four specific industries assumed to lead, between 2023 to 2038, the expansion of w, z, and f industries. To keep the estimations as realistic as possible, benchmarks from current plants in Colombia and Brazil were used to compare the specifications of the estimated “typical plants”. Once benchmarked, the figures of capacity production of the “typical plants” were used for estimating the number of these plants needed to comply with the EECP in specific industries of the markets modelled in the CFSM-I. The estimated number of plants was also benchmarked against Chile’s indicators of the forest industry.

For complying with the EECP of the Colombian wood forest products industry during the second period of the policy implementation (2023-2030), and based on “typical plants”, Colombia would need to install 20 additional modern sawmills (including kiln-dry ovens) for processing 220,000 m^3rsc/year per plant, 13 more Medium Density Particle (MDP) plants with capacity to process 243,000 m^3rsc/year each, 2 dissolving new wood pulp plants processing 2,000,000 m^3rsc/year each and 40 other plants of RTA furniture, each able to consume 24,000 m^3 of wood-based panels/year. For the second period of the PFCm policy implementation (2031-2038), the number of additional plants of the same type and with the same capacity production that Colombia should deploy to comply with the EEPC would reach 34, 4, 1 and 60, respectively.

The number of plants mentioned above, the characteristics of the industrial facilities named here “typical plants”, and the benchmarks used to keep the estimations realistic are summarized in Table 7-6. At this time, it is important to keep in mind that the specific industry capacity expansion presented in this subsection and condensed in Table 7-6 does not imply that, in practice, must also be the case for the industry expansion in Colombia, but rather that the figures readily permit the retrieval of information for estimating the size of the shocks on Labor and Capital required for running the simulations of Category II. It is crucial to account for forest stakeholders in Colombia having other views on how to implement the industry expansion. For example, they could decide to deploy half of the number of plants for any of the industries under consideration and increase the size of the production capacity of each plant, or vice versa.

3. Estimation of the size of the shocks on L and K variables. The number of plants needed to comply with the EEPC multiplied by the investment in Machinery & Equipment and Buildings & Structures, and the number of employees in three shifts of operation (production and administrative) of a “typical plant” results in the size of the shock for each of the individual industries. As the wood industry (w) is the sum of the sawnwood and the wood-based panels industries, the size of the shock for w is the aggregation of the sizes of the shocks of their individual industries. The results of these operations are presented in Table 7-7.

If 174 “typical plants” of the sawn wood, pulp & paper and wooden furniture industry are deployed in Colombia during 2023 to 2038, the investments and direct employment in the wood forest industry would increase by 17,092 2015-thousand million COP (6,2 2015-billion USD) and 36,340 new jobs. Although 70% of the investment would happen in the pulp & paper industry, only 12% of the direct jobs would be generated in that in that industry. On the contrary, with only 10% of the total investment in the furniture industry it would generate 63% of the direct employment. Also, with 20% of all investments of the manufactured wood forest products, the wood industry (sawn wood and wood-based panels) would generate 25% of the total employment, a bit more than double of that of the pulp & paper industry. These shares confirm the general knowledge that the pulp & paper industry is a capital-intensive industry, the furniture industry is more of the kind of labor-intensive industry and the wood industry is in the middle of these two types.

4. Determination of the implementation time for the shocks in the CFSM-I. Finally, as per how the period-aggregated shocks of Table 7-7 would be implemented through the years of simulation, it was decided to pair these with the VAS estimated from forest plantations of scenario S4, whose goal is increasing the forest plantations area in Colombia to reach 1.5 Mha by 2025.

The aim of this paring was to avoid any shortages of unprocessed wood from forest plantations needed to fulfill the demand of the plants deployed during any particular year for the period of simulation. The number of plants for each industry of the markets modelled in the CFSM-I, investment, and their employment generated are presented in Table 7-8.

Table 7-6 Plants, Capital investments in Machinery & Equipment and Building & Structures, and Employment for the expansion on production capacity of the manufactured wood forest products industry

Item	Industry modelled in the CFSM-I	Wood industry (w)		Pulp & paper industry (z)	Furniture Industry (f)
	Specific Industry	Sawnwood	Wood-based panels	Wood pulp	Wooden Furniture
	Main product	Kiln-dried planned sawn wood[1]	Medium Density Paticle Board[2]	Wood pulp[3]	Ready to Assamble (RTA) furniture[4]
New plants (operating 3 shifts)	Production capacity (Intake of wood in m^3rsc/year)	220 000	243 000	2 000 000	24 000 m3 of wood-based panels
	Production capacity (Output of main product m^3/year)	100 000	180 000	500 000 tons of disolving wood pulp & 144 MW of clean energy	480 000 wooden-furniture units
	Machinery & Equipment (2015 thousand million COP)	3.19	167	3 685	
	Building & Structures (2015 thousand million COP)	0.75	16	320	
	Machinery & Equipment + Building & Structures (2015 thousand million COP)	3.94	184	4 006	17.4
	Machinery & Equipment + Building & Structures (2015 million USD)	1.44	67	1 461	6.3
	Production & Administration Employees (number of people)	100	220	1 400	230
	Additional plants needed to comply with EEPC at 2030 (Number)	20	13	2	40
	Additional Plants needed to comply with EEPC at 2038 (Number)	34	4	1	60
	Total additional Plants needed to comply with EEPC at 2038 (Number)	54	17	3	100
Bechmarking (Typical current plants operating 3 shifts)	**Colombia (medium- and large-size plants)[4]**				
	Production capacity (Intake of wood in m^3rsc/year)	55 000	243 000	1 000 000	24 000
	Output per year	5 000 to 25 000	72 000 to 180 000	250 000	480 000
	Units of output	m3 of kiln-dried sawn wood	m3 of wood-based boards (MDP and MDF)	tonnes of wood pulp	wooden-furniture units
	Notes	Intake of wood was estimated for an output of 25 000 m3 of kiln-dry sawn wood	Intake of wood was estimated for an output of 180 000 m3 of boards	None	Intake of wood was estimated for an annual output of 480 000 units of wooden-furniture units using data from a RTA furniture plant located in the municipality of Guarne, Antioquia Departamento of Colombia which process 12.000 m3 of wood based panels a year to produce aprox. 240 000 units of furniture a year.
	Chile and Brazil[5]				
	Production capacity (Intake of wood in m^3rsc/year)	540 000	450 000	3 900 000	
	Output per year	100 000 to 500 000	300 000	500 000 to 2 000 000	
	Units of output	m3 of sawn wood	m3 of wood-based boards	tonnes of wood pulp	
	Area of forest plantations to comply with the intake of wood (ha)	18 000	15 000	130 000	
	Forest plantation productivity (IMA in m^3/ha per year)	30	30	30	
	Species	Pinus spp.	Pinus spp. or Eucalyptus spp.	Eucalyptus spp.	
	Notes	The area of forest plantations is to support an output of 250 000 m3 of klin-dried and planned sawn wood a year	The output is for a plant with several lines of production combined, each line with a capactity production of 300 000 m^3 of boards	The area of forest plantations is to support an output of 1 000 000 tonnes of wood pulp a year	
	Chile's plants (Number in 2021)[6]	1 234	27	12	
	Chile's Production in 2021 (Intake of wood Mm^3rsc in 2021)[6]	16.73	4.82	16.09	
	Chile's Production in 2021 (Outuput in million m^3 for sawn-wood and wood-based panels and tonnes for wood pulp)[6]	8.68	3.57	4.98	
	Chile's Installed Production capacity in 2021 (Outuput in million m^3 for sawn-wood and wood-based panels and tonnes for wood pulp, 3 shifts)[6]	26.77	4.16	5.82	
	Notes for Chile[6]	Permanent sawmills 509 units (41%), Mobile sawmills 725. Seven sawmills produce more than 300.000 m3/year each (aprox 32% of national production). Seventeen produce more than 100.000 (54,5% of national production). There were 774 swamills that produce less than 5000 m3/year. Biggest Intalled capacity sawmills 690 000 m3 of sawnwood in three shifts.	In 2021, four firms represented 80,3% of the installed production capacity (In 2018, 4 plants respresented 52% of installed production capacity). For 2021, national consumption of wood-based industry 4,82 Mm^3rsc (aproximately 11,2% of all logs consumption of the forest industry), 3.13 Mm^3rsc were plywood logs to produce 1.49 Mm3rsc of plywood and veneers. This industry also consumed chips (952.100 m^3) and sawndust (305.100 m^3)	In 2021, the installed capacity per plant ranged from 70 000 to 1 500 000 tonnes of wood pulp/year. Out of 12 plants 3 have a production capacity less than 150 000 tonnes/year, 7 between 290 000 to 550 000 tonnes/year and 2 have 1 070 000 and 1500 000 tonnes/year respectively. 90% of the Chile's installed capacity is for producing Chemical pulp	

Source: This research. The estimations in this table are based on data from: [1]López and Cornet (2018) and Merle and López (2018) for new plants in the sawnwood industry; [2]Merle and López (2018a) and Primadera (2016) for new plants in the wood-based panels industry; [3]LD Celulosa (2022 and 2022a) for new plants in the wood pulp industry, [4]RTA Muebles (2021) and Arias (2008) for new plants in the Wooden Furniture, [5]Held et al.(2017); [6]INFOR (2019) and Soto et al, (2022) for the wood-based panel industry, Alvarez-González et al. (2021) for the sawn wood industry, González et al. (2021) for the wood pulp industry for Chile

Table 7-7 Shock sizes on Labor (L) and Capital (K) of the CFSM-I simulations of Category II of Policy Experiments (L in number of people, K in 2015 thousand million COP, unless otherwise stated)

Colombian manufactured wood (forest) products industries modeled in the CFSM-I	**2020***		**2023 - 2030****		**2031 - 2038****		**2023-2038 Total additional L and K**		**Total L and K in 2038**	
	L	**K**	**L**	**K**	**L**	**K**	**L**	**K**	**L**	**K**
Wood industry (w)	4 750	668	4 860	2 467	4 280	869	9 140	3 336	13 890	4 003
Pulp & paper industry (z)	18 085	5 605	2 800	8 012	1 400	4 006	4 200	12 017	22 285	17 623
Furniture Industry (f)	14 451	1 508	9 200	696	13 800	1 044	23 000	1 739	37 451	3 247
Total manufactured wood (forest) products industry	**37 286**	**7 781**	**16 860**	**11 174**	**19 480**	**5 918**	**36 340**	**17 092**	**73 626**	**24 873**
Total investment in 2015-million USD		2 838		4 075		2 158		6 234		9 072

* Last year of available actual data is 2020. In the CFSM-I, L is represented by industry's total employees in the annual manufacturing survey (in Number of people) and K is represented by the value of Machinery & Equipment and Buildings & Structures in the annual manufacturing survey, at end of the year (in 2015 thousand million COP) based on DANE (2022c). ** L and K for 2023 -2030 are additional to the 2020's, and 2023 -2038's is additional to the 2023- 2030's.

Table 7-8 Labor and Capital shock sizes and time for simulation of Category II of Policy Experiments (L in number of people, K in 2015 thousand million COP, unless otherwise stated)

Year	Total Availability of wood from thinnings and final harvest for S4 PNDF/PAPFCm 1 (Mm^3rsc/year at the end of the year)	Availability of wood for Sawnwood S4 PNDF/PAPFCm 1 (Mm3rsc/year at the end of the year)	Availability of wood for wood-based panels, pulp, forest bioenergy or innovative manufactured wood forest products S4 PNDF/PAPFCm1 (Mm3rsc/year at the end of the year)	Expected Expansion Production Capacity - EEPC (new plants)																								Availability of wood from thinnings and final harvest for S4 PNDF/PAPFCm1 (Mm^3rsc/year at the end of the year) after discounting consumption of new plants	Availability of wood from thinnings and final harvest for S4 PNDF/PAPFCm1 (Mm^3rsc/year at the end of the year) after discounting consumption of new plants and current plants*
				Wood industry (w)												Pulp & paper industry (z)				Furniture Industry (f)				Total wood forest products industry					
				Sawnwood				Wood-based panels				Total w																	
				Plants (number)	Cumulated Consumption of wood (Mm^3rsc/year)	L	K	Plants (number)	Cumulated Consumption of wood (Mm^3rsc/year)	L	K	Plants (number)	Cumulated Consumption of wood (Mm^3rsc/year)	L	K	Plants (number)	Cumulated Consumption of wood (Mm^3rsc/year)	L	K	Plants (number)	Cumulated Consumption of wood (Mm^3 wood-based panels/year)	L	K	Plants (number)	Cumulated Consumption of wood, excluding furniture (Mm^3rsc/year)	L	K		
2015	2.9	1.7	1.2																										
2020	2.9	1.3	1.6																										
2022	5.0	1.8	3.2																										
2023	7.2	2.8	4.4	5	1.1	500	19.71	4	1.0	880	735	9	2.1	1380	755					4	0.1	920	70	13	2.1	2 300	824	5.1	2.1
2024	9.4	4.0	5.4	4	2.0	400	15.77	4	1.9	880	735	8	3.9	1280	751					4	0.2	920	70	12	3.9	2 200	820	5.5	2.5
2025	11.1	4.0	7.1	3	2.6	300	11.82	3	2.7	660	551	7	5.3	960	563	1	2.0	1 400	4006	5	0.3	1 150	87	12	7.3	3 510	4 656	3.8	0.8
2026	13.3	4.7	8.6	3	3.3	300	11.82	2	3.2	440	367	6	6.5	740	379		2.0			5	0.4	1 150	87	10	8.5	1 890	466	4.8	1.8
2027	17.6	6.6	11.0	4	4.2	400	15.77		3.2			2	7.3	400	16	1	4.0	1 400	4006	5	0.6	1 150	87	10	11.3	2 950	4 109	6.3	3.3
2028	20.0	7.1	12.8		4.2				3.2			2	7.3				4.0			5	0.7	1 150	87	5	11.3	1 150	87	8.6	5.6
2029	20.5	8.1	12.4		4.2				3.2			1	7.3				4.0			6	0.8	1 380	104	6	11.3	1 380	104	9.2	6.2
2030	21.4	9.4	11.9		4.2				3.2			1	7.3				4.0			6	1.0	1 380	104	6	11.3	1 380	104	10.1	7.1
2031	25.2	12.4	12.7	15	7.5	1 500	59.12	4	4.1	880	735	19	11.6	2380	794	1	6.0	1 400	4006	7	1.1	1 610	122	27	17.6	5 390	4 921	7.6	4.6
2032	27.5	15.5	11.9	15	10.8	1 500	59.12		4.1			15	14.9	1500	59		6.0			7	1.3	1 610	122	22	20.9	3 110	181	6.6	3.6
2033	29.5	16.0	13.4	5	11.9	500	19.71		4.1			1	16.0	500	20		6.0			7	1.5	1 610	122	12	22.0	2 110	141	7.5	4.5
2034	31.9	19.1	12.7		11.9				4.1			0	16.0				6.0			7	1.6	1 610	122	7	22.0	1 610	122	9.9	6.9
2035	23.3	12.6	10.7		11.9				4.1			0	16.0				6.0			8	1.8	1 840	139	8	22.0	1 840	139	1.3	- 1.7
2036	25.4	15.2	10.1		11.9				4.1			0	16.0				6.0			8	2.0	1 840	139	8	22.0	1 840	139	3.4	0.4
2037	15.6	7.0	8.6		11.9				4.1			0	16.0				6.0			8	2.2	1 840	139	8	22.0	1 840	139	- 6.4	- 9.4
2038	18.7	8.8	9.8		11.9				4.1			0	16.0				6.0			8	2.4	1 840	139	8	22.0	1 840	139	- 3.3	- 6.3
2040	30.9	19.0	11.8		11.9				4.1				16.0				6.0				2.4				22.0			8.9	5.9
2045	22.7	12.3	10.3		11.9				4.1				16.0				6.0				2.4				22.0			0.7	- 2.3
2047	26.8	15.3	11.4		11.9				4.1				16.0				6.0				2.4				22.0			4.7	1.7
Total	665	367	296	54	12	5 400	213	17	4	3 740	3 123	71	16	9 140	3 336	3	6	4 200	12 017	100	2.4	23 000	1 739	174	22.0	36 340	17 092		

Sums could not match its addends because of approximations * Current volume sourced in forest plantations as of 2023 would be around 3,0 Mm^3rsc/year.

7.2.3 Restrictions, adjustments, and additional assumption of the CFSM-I for running the policy experiments

In implementing the policy experiments of Category I, the CFSM-I (as it was built, i.e., without any constraints) was simulated for obtaining the *ex-ante forecast* (2021-2047) of all its endogenous variables. As expected before running the model, these simulations without restraints resulted, in part, in output without economic meaning, e.g. positive extreme values and negative values of the endogenous variables. They also resulted in non-clearing of the markets for several years.

To eliminate meaningless forecasts from the simulation output and achieve market clearing, some restrictions were imposed on the CFSM-I. For the former, the usual constraints, such as benchmarks (lower and upper bounds) and relations between prices, were activated to rule out negative and extreme values of the endogenous variables. For the latter, the equations for the endogenous variables of imports (M) for w, f , and z, and that of exports (X) of the MWrw market were "turned off". These M and X variables, in addition to the variables of prices of supply (PS), were subject to adjustments for achieving the clearing situation of the markets.

It was assumed that M^{Mwrw} for 2021-2047 would be zero, hence, in the market clearing identity of the MWrw market, the M^{Mwrw} addend was always equal to zero. The first reason for this was that M^{Mwrw} equation did not perform well in isolation nor in the context of the isolated market of MWrw or the connected markets (i.e., the complete CFSM-I, see section 5-5 in chapter 5). The second reason was that the 1975-2020 actual values of M^{Mwrw} have been mostly zero or marginal. A third reason is that, in 2015, the level-price of imports of wood pulp, chips and saw logs for Colombia are relatively high compared to the domestic prices of Colombian MWrw, hence it is not expected that Colombian manufacture producers will import MWrw for producing these three products.

7.3 Results and Discussion

For both categories of policy experiments explained in section 7.2, the simulations of the CFSM-I produced an *ex ante forecast* for the key variables of the Colombian Forest Sector in the period 2021-2047. For each of the six and five scenarios of Category I and Category II, respectively, annual values of the forecast were obtained for the supply (S), consumption (C), exports (X) and imports (M) of the Colombian markets of manufactured wood products of the wood (w), furniture (f) and pulp & paper (z) industries, and their deflators PS, PC, PM, and PX. Annual values were also generated for the same variables for the Colombian market of unprocessed wood for the manufactured wood products industry & for final use other than firewood (MWrw) [77].

7.3.1 Simulations for Category I of policy experiments

The 2021-2047 forecasted monetary values of S, C, X, M and their deflator prices PS, PC, PM, PX for the MWrw, w, f, and z Colombian markets, under the alternative policy scenarios of Colombia´s forest plantations area expansion (S1 to S6) are presented in Figures 7-1 to 7-6. These values were obtained for the market clearing situation in all four markets connected, i.e., acting as a unit (the wood forest product (WFP) market).

For comparison, actual data from 1975 to 2020 has been added to each of the three panels of every scenario in the figure: (a) S, C, X, M, (b) PS, PC, PM, PX, and (c) the results of market clearing outcome expressed as (Supply-Demand)/Supply, in percentage. Also, data for key years (2015, 2020, 2022, 2030, 2038 and 2047) have been added to the figures to help readers (especially policy makers and other Colombian stakeholders) analyze them separately, without resorting to other parts of this dissertation. Data for 2015 is important as the CFSM-I is built in 2015-constant prices. Data for 2020 is significant for two reasons: first, this is year when the world economy was severely hit by the COVID19 pandemic (Colombia and its forest sector were not exempt from this crisis); second, 2020 was the latest year for which data for the Colombian forest sector was available at the time the experiments were run (i.e., 2020 was the “present” in the CFSM-I). Data for 2022, 2030 and 2038 is crucial, as these years are the final year of the three periods of implementation of the (2018-2038) PFCm policy. Finally, data for 2047 is valuable as this is the final year of the forecast, that coincides with the year in which all stands in scenarios S1 to S5 of

[77] In the CFSM, Supply (S) is the National Production and the Demand (D) is defined as the sum of Consumption (C) plus Exports (X) minus Imports (M).

PFCm area expansion would have completed, at least, the first rotation period under sustained management.

Aside from the values of the endogenous variables being ≥ 0 and the PS^{MWrw} being ≥ 0.3, PS = PC in all markets, the absence of imports in the MWrw market, the bounds of Supply of w, z, and f because of the installed production capacity of the respective industries, no other restrictions were imposed on the CFSM-I simulations to produce the output of figures 7-1 to 7-6. For yielding the market clearing case in all markets, under the restrictions imposed, the equations of X^{MWrw}, M^w, M^f, and M^z were “turned off” and the model was allowed to make adjustments (i.e., iterate) not only on the PS but on these four endogenous variables. Except for the exogenous variable VAST, which is different in all six scenarios due to the distinct VAS per scenario S1 to S6, all else was equal in the simulations that generated the results shown. All else equal, in the context of the experiments presented in this chapter, means that all other CFSM-I exogenous variables have the same annual values for the period 2021-2047 when scenarios S1 to S6 were run. For the discussion that follows, S1 corresponds to the base scenario.

Figure 7-1 2021-2047 forecasted values for supply, Consumption, Exports and Import and their prices for the Colombian wood forest products markets under scenario S1 (0.3 Mha Colombia's commercial plantations maintained to perpetuity) – Category I of Policy Experiments

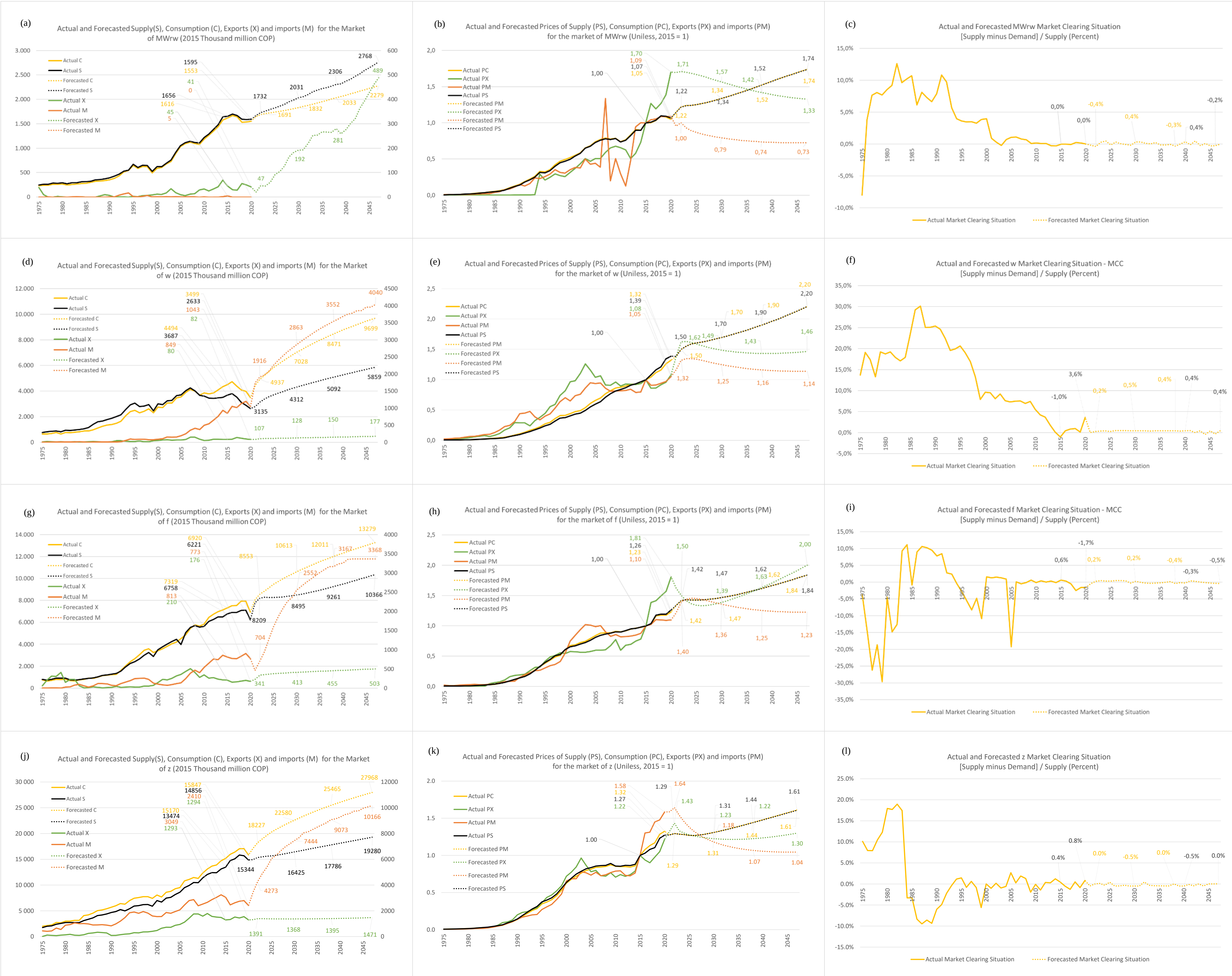


Figure 7-2 2021-2047 forecasted values for supply, Consumption, Exports and Import and their prices for the Colombian wood forest products markets under scenario S4 (1.5 Mha Colombia's commercial plantations, to be reached in 2025, maintained to perpetuity) – Category I of Policy Experiments

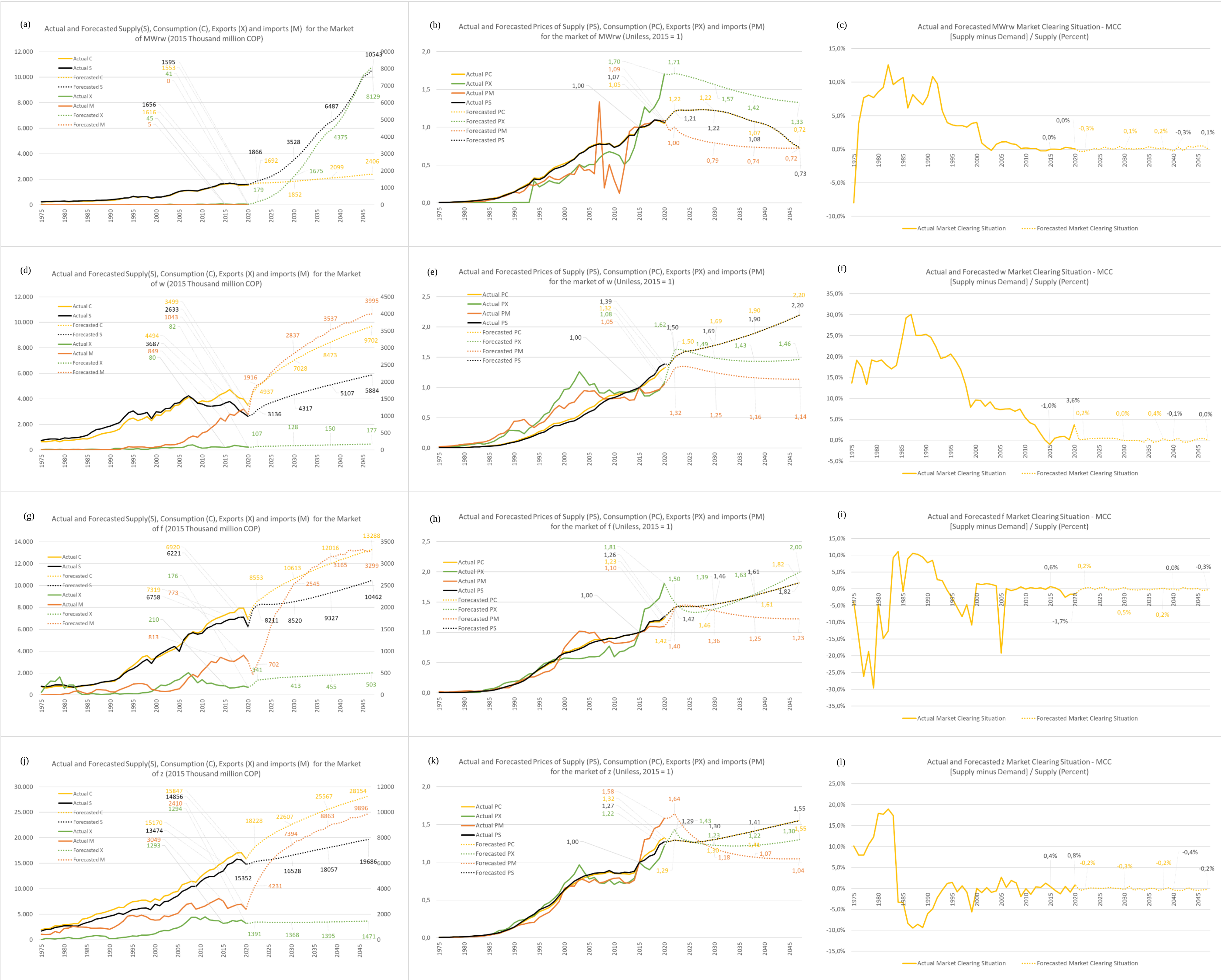


Figure 7-3 2021-2047 forecasted values for supply, Consumption, Exports and Import and their prices for the Colombian wood forest products markets under scenario S2 (0.45 Mha Colombia’s commercial plantations maintained to perpetuity) – Category I of Policy Experiments

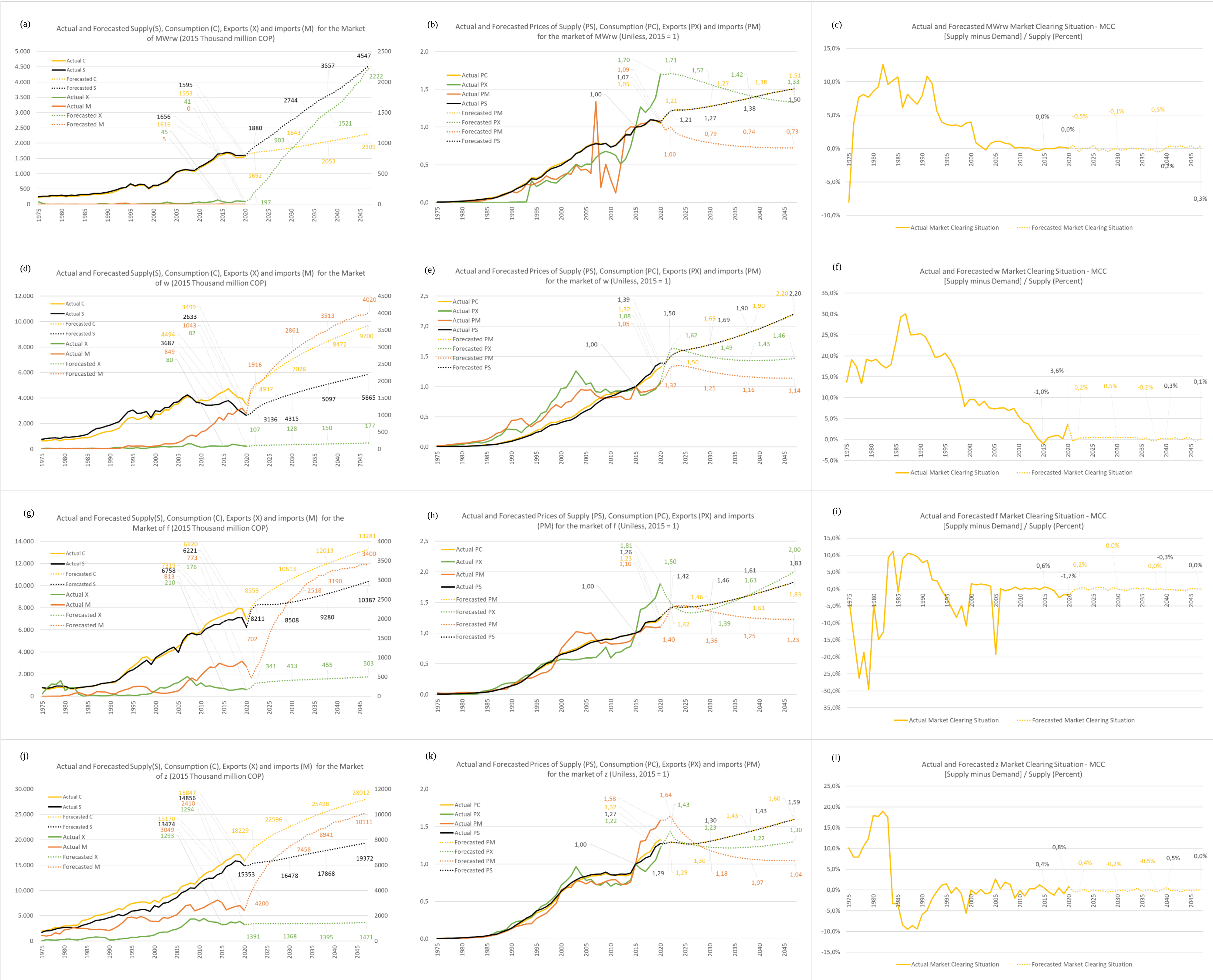


Figure 7-4 2021-2047 forecasted values for supply, Consumption, Exports and Import and their prices for the Colombian wood forest products markets under scenario S3 (0.765 Mha Colombia's commercial plantations, to be reached in 2035, maintained to perpetuity) – Category I of Policy Experiments

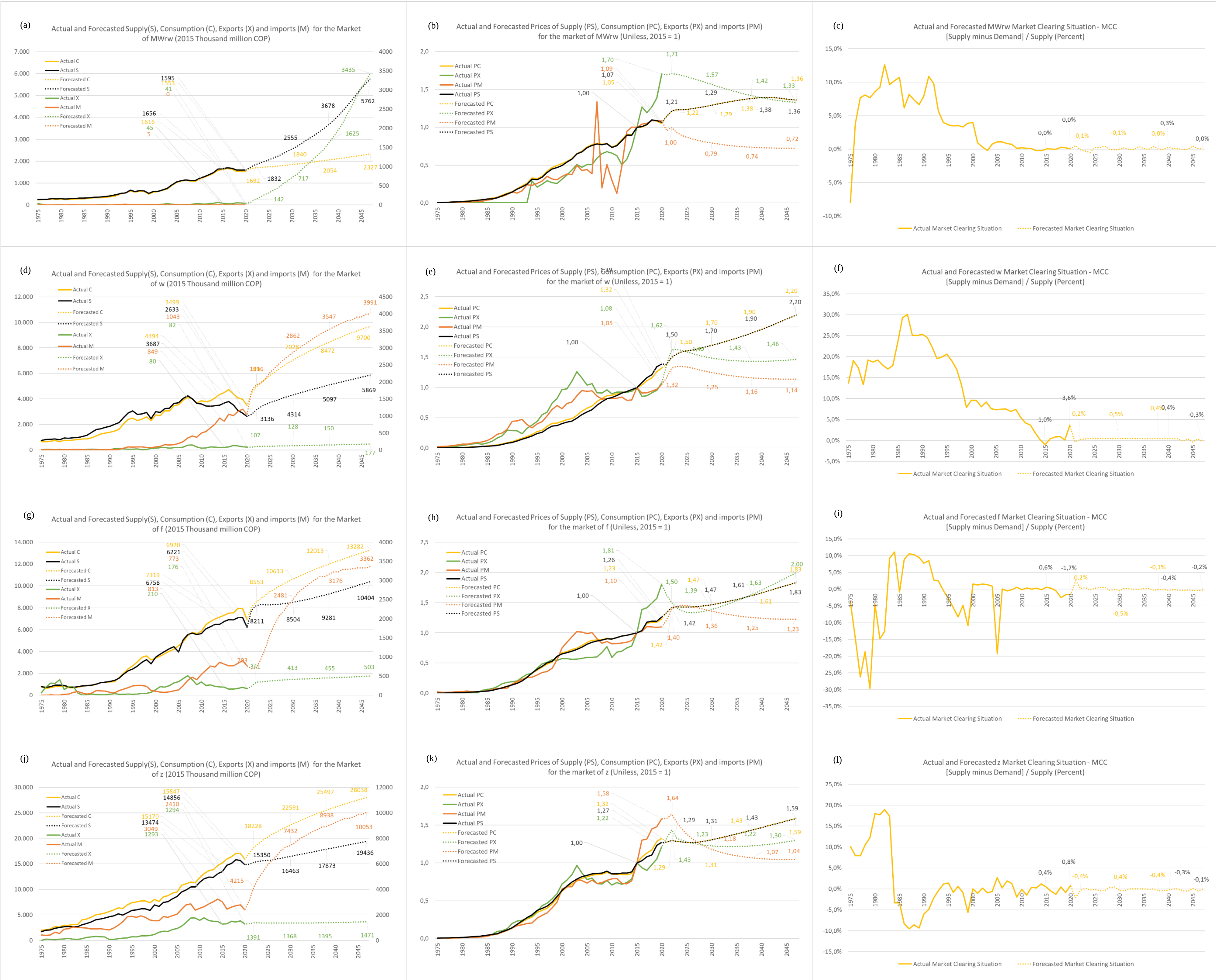


Figure 7-5 2021-2047 forecasted values for supply, Consumption, Exports and Import and their prices for the Colombian wood forest products markets under scenario S5 (2.0 Mha Colombia's commercial plantations, to be reached in 2025, maintained to perpetuity) – Category I of Policy Experiments

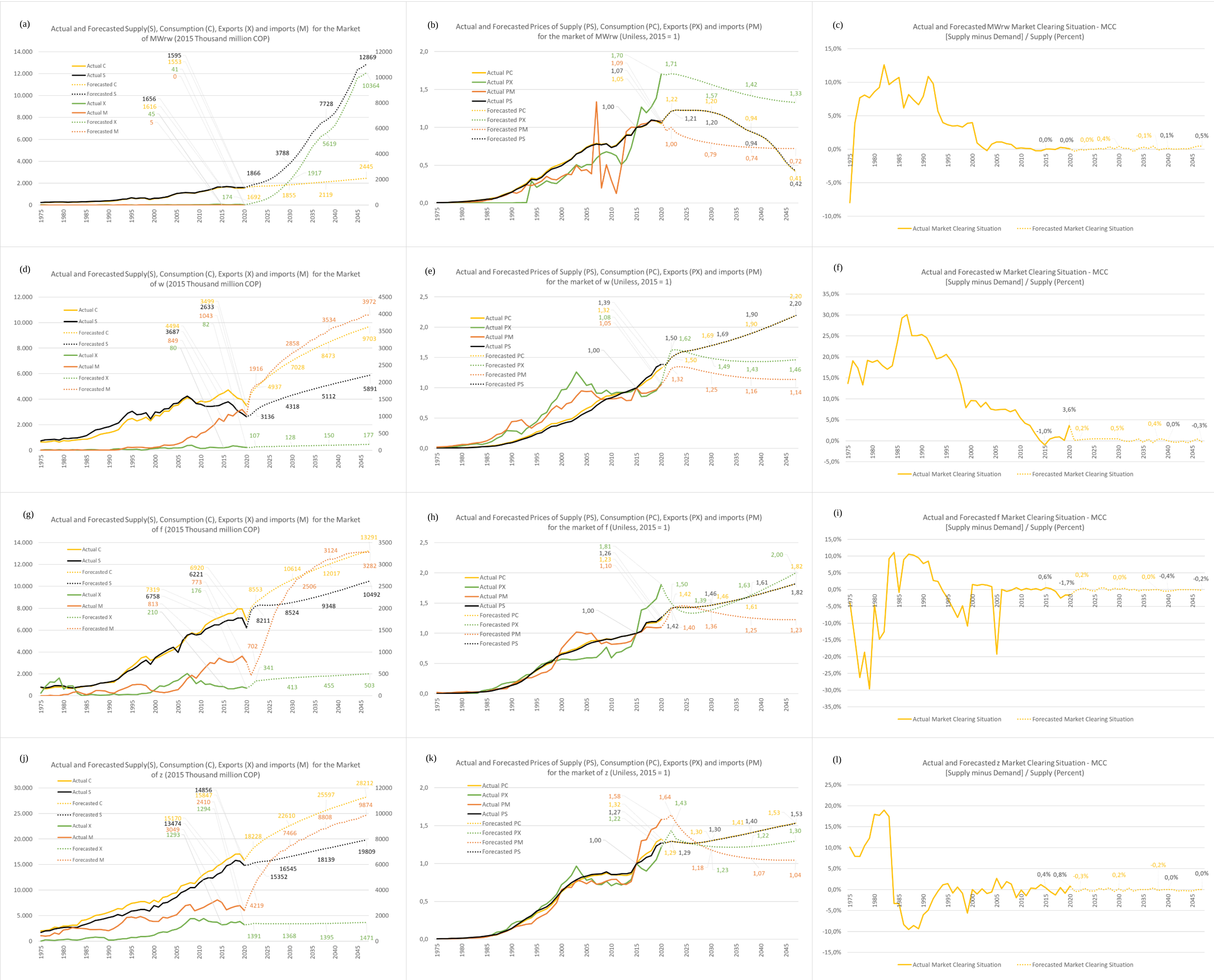
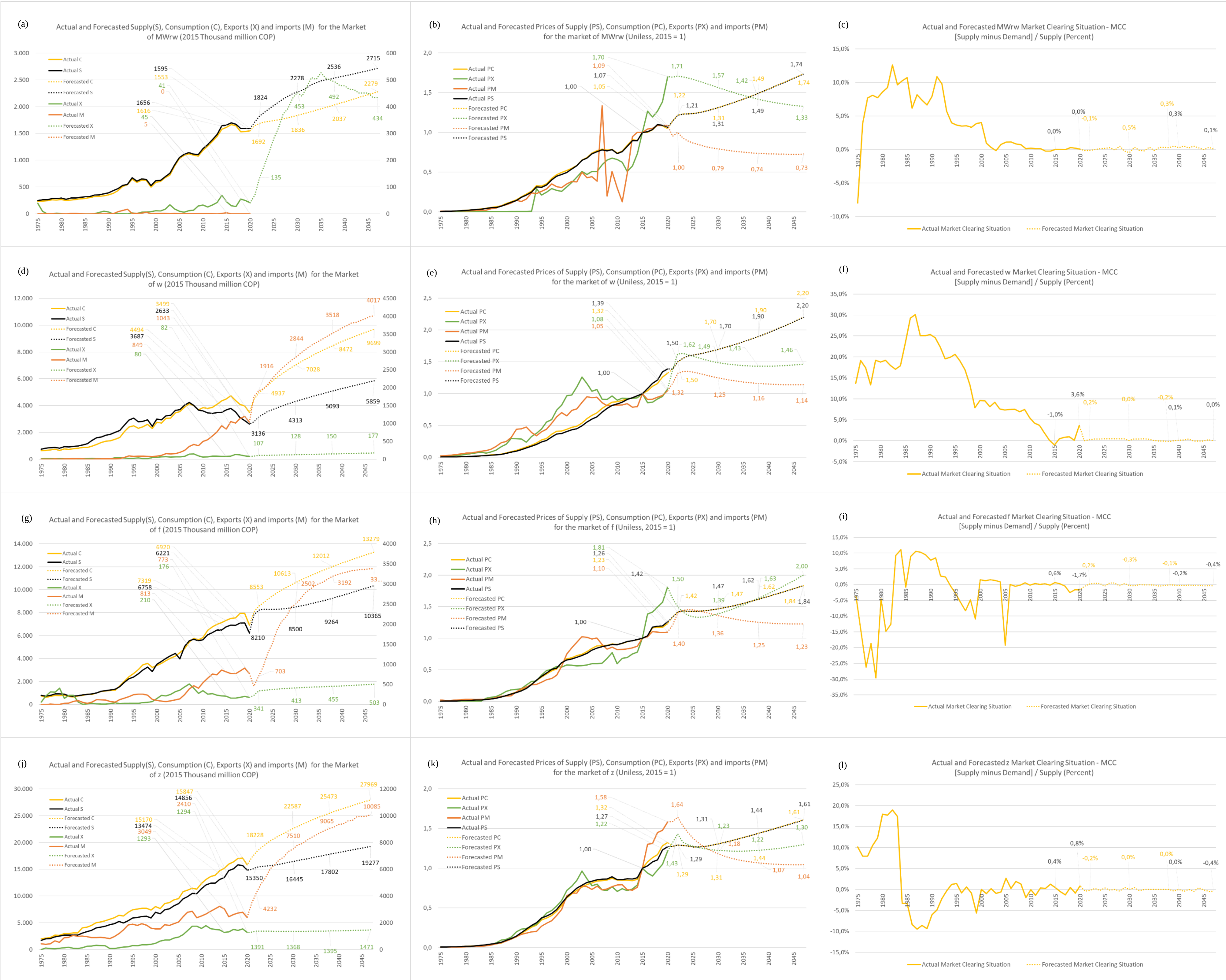


Figure 7-6 2021-2047 forecasted values for supply, Consumption, Exports and Import and their prices for the Colombian wood forest products markets under scenario S6 (0.3 Mha Colombia's commercial plantations harvested without replacement) – Category I of Policy Experiments



7.3.1.1 Colombian markets of wood forest products under scenario S1

Simulation results for the scenario when 0.3 Mha of Colombian PFCm is maintained in perpetuity (base scenario (S1)) are summarized in Figure 7-1. Panels in the first and second column of this figure represent the solution found for the market clearing case during 2021-2047, for each of the four CFSM-I partial equilibrium models that represent the markets of MWrw, w, f, and z, (panels c, f, i, l)[78].

Under S1, for all four markets, the national Consumption (C) is projected to increase relatively fast during the next 25 years (panels a, d, g, l). The model predicts that the levels of C for products traded in MWrw, w, f, and z markets, respectively, would increase by 48%, 142%, 67% and 64% with respect to (w.r.t.) those of 2019. This includes the recovery from the worst point of the COVID19 pandemic in 2020, during which, the MWrw market experienced only a 1% growth, and the remaining three markets, in that order, suffered declines of 12%, 13% and 7% from 2019 levels.

By the end of the first period of implementation of the PFCm policy (2022), the model forecasts that C of the furniture and pulp & paper products would experience a slight growth, by around 7% each w.r.t. 2019 levels, which were 7,928 and 17,067 2015-thousand million COP (2015tmCOP), respectively. Meanwhile, C of unprocessed wood (excluding that for firewood) and of the products of the wood industry (sawn wood and panels, mainly) would rise by 10% and 24% w.r.t their 2019 levels of 1,573 and 3,984 2015tmCOP, correspondingly. By the end of the second period of the PFCm policy implementation (2030), the consumption of f and z would have multiplied by 1.3 w.r.t. their 2019 levels, and the C of w and MWrw would be 1.7 and 1.2 times their levels in 2019. When the policy completes the last period of implementation (2038), the level of consumption of the these products, in the same order, would reach 12,011, 25,465, 8,471 and 2,033 2015-

[78] A solution is a set of prices PS, PC, PM and PX that makes S-D = 0 (or close to zero). It is worth keeping in mind that CFSM-I uses Excel Solver® to find the solutions of its four partial equilibrium models (MWrw, w, f, and z) and that to comply with the identity of the Market Clearing Condition all adjustments are made in the CFSM-I on the price of supply of each of the four markets modelled (MWrw, w, f, and z).

tmCOP, respectively (around 1.5 times their 2019-levels for f and z, and more than double and 1.3 times for w and MWrw, correspondingly)[79].

The explained 2021-2047 Colombian consumption of the wood forest products would be met by a combination of the domestic supply (national production) and imports: Both in the case of the manufactured wood products of the wood, furniture and pulp & paper industry, and only domestic supply (S) in the case of unprocessed wood.

Regarding domestic supply (in this research shortened just as Supply and abbreviated as S), it is also projected to increase in the period 2021-2047. S would grow less than C in the manufactured wood products markets (i.e., the markets of w, f and z) and more than C in the MWrw market. In each of these markets, the forecasted S tracks the path of the forecasted C, similarly as it has historically been the case for MWrw (S > C) and z (S < C), and since around 2010, for w and f (S < C). In the markets of w, f and z, during the period of simulation, the negative distance between C and S, which signals a shortfall of capacity production of the national industry of wood forest products, would widen. In the succeeding 25 years, these distances, already important in 2020, would amplify to 8,687 2015tmCOP for z, 3,839 2015tmCOP for w and 2,912 for f. On the contrary, in the market of MWrw an oversupply is forecasted during the whole period of simulation, situating the positive distance between them by 2047 at 490 2015tmCOP.

Despite the restrictions of installed capacity (represented by the Labor and Capital variables in the equations of supply of w, f, and z, and the variable VAST in the equation of supply of MWrw coming from forest plantations), the increase in supply of w and MWrw would multiply their corresponding 2019-levels of supply by around 2.0 and 1.7 by the end of 2047. For the MWrw, the share of supply sourced in the forest plantations will continue to slowly increase from around 60% in 2021 to around 68% in 2047. Throughout the same period, the supply of f would multiply by 1.4, while the supply of z would grow 1.3 times w.r.t. the 2019-levels, respectively. All these

[79] One should keep in mind that the periods of implementations of the PFCm policy, and their corresponding end years (2022, 2030 and 2038) are used in S1 as a reference for scenario 4 (S4). S1, as fully explained in chapter 6, corresponds to a kind of “business as usual scenario” for which it is assumed that the PFCm policy would either not exist or is not implemented.

relatively small changes would happen at steady pace, as shown in panels a, d, g and j of Figure 7-1. For example, by the end of 2022, 2030 and 2038, the supply levels of w would be 3,135, 4,312 and 5,092 2015-tmCOP, those of f would reach 8,209, 8,495 and 9,261 2015-tmCOP and the supply levels of z would get to 15,344, 16,425 and 17,786 2015-tmCOP. Historically, national producers of manufactured wood forest products have increased their capacity production very slowly, and the CFSM-I might have inherited that pace to forecast the supply, as the figures presented seem to reveal. The issues pertinent in the Colombian forest industry are discussed in depth in Appendices 4-3 and 4-2 of chapter 4.

Concerning the imports (M) and exports (X), except for the exports of z, both are projected to grow in all the markets. The biggest increase of M would happen for the products of the furniture industry (272% w.r.t. 2019 levels) reaching a value of 3,368 2015tmCOP by 2047. In turn, the imports of products of the pulp & paper industry and the wood industries will reach 10,166 and 4,040 2015tmCOP by the same year, representing a 265% and 272% increase w.r.t. their 2019-levels. For exports, although the level values for w and f would increase by 82% and 147% by 2047, they would continue being marginal w.r.t. the supply values of these products (3.0% and 4.9%). Exports of z would remain at around the same level from 2021 to 2047, and compared to their 2019-levels, they would decrease by 5% by 2047. As for the other wood forest products, exports would remain negligible when compared to the supply of these products, around 7.6%. On the contrary to the z exports, the oversupply in the market of MWrw, mentioned above, would allow for the exports of MWrw to rapidly grow during the period of simulation, reaching a level of 489 2015tmCOP in 2047 (a rise of 878% from the level of exports of MWrw in 2019).

With regards to prices, under S1, the supply price (PS) is projected to significantly increase across all markets in the next 25 years (panels b, e, h, k of Figure 7-1). Meanwhile, the PS of unprocessed wood would increase by almost 75% and both the PS of the manufactured products of the furniture industry and the pulp & paper industry would rise by 82% and 61%, the PS of the manufactured wood products of the wood industry would have a 120% increase (all the percentages w.r.t. their respective level in 2015).

In turn, the prices of exports (PX) and the prices of imports (PM) of w and z are expected to increase during the first years of the simulation and then decline until they become relatively stable for most of the latter years. PM for f is also forecasted to follow the same trend. For MWrw, both PX and PM are projected to fall during the whole period of simulation, resulting in 33% more and 27% less than their corresponding levels of 2015. For the PX of manufactured wood products of the furniture industry the trend is to fall rapidly until 2027, and then rise steadily until 2047.

7.3.1.2 Colombian markets of wood forest products under scenario S4

Jointly to S1, the scenario that expands the current area of Colombian PFCm, 0.3 Mha, to 1.5 million ha by 2025, and maintains it in perpetuity (i.e., S4) are the most important for the policy makers and other stakeholders of the forest sector in Colombia. As explained before, S4 represents one of the most important PCFm policy commitments, a goal that is currently under implementation. As such, the discussion and the results of S4 are presented before, and more in depth than the results for scenarios S2, S3, S5 and S6, whose results are only summarized, comparatively, in table 7-9 at the end of this subsection.

Just as in S1, for scenario S4, the panels in the first two columns of Figure 7-2 summarizes the solution found by the market clearing case in the four markets comprising the Colombian wood forest products (panels c, f, i, l). On the contrary to how figures were discussed for S1, S4 and the rest of the scenarios are examined comparatively to S1. As the only difference in the simulations to obtain the outputs of S1 and S4 was the VAS (and in consequence the VAST), part of the S1 output compared to the output of S4 is the same (e.g. X^w, PX^w, X^f, PX^f, X^z, PX^z and PX^{MWrw}) or very similar, i.e., the forecasted values changed by less than 2.5% (C^{Mwrw}, S^w, C^w, M^w, PC^w, PM^w, S^f, C^f, M^f, PC^f, PM^f, S^z, C^z, and PM^z). Hence, figures corresponding to these variables are excluded from discussion.

A change in Colombia's PFCm area maintained to perpetuity from 0.3 Mha (S1) to 1.5 Mha, will multiply the volume of wood available for supply in this source, during the period 2021-2047, by around 5 times (116 vs 625 Mm^3rsc). All else equal, this important rise in the supply of wood from PFCm is projected to affect, largely, the MWrw market and, marginally, the markets of z and f.

In order to simplify the writing, hereafter all values refer to S4. Values are rounded up to the 0.5 closest number. Unless otherwise specified, the comparative figures without any reference for any variable represent a comparison of the S4 values to S1 values, and they are expressed and compared, on average, for the period 2021 to 2047. Also, mentions of both the level values and Figures 7-2 or 7-1 are reduced to the minimum. Level values in key years are shown in the same figures, and the reader can refer to Appendix 7-2 for annual values.

For the MWrw market, the significant impacts of a larger availability of PFC unprocessed wood (S4) would be on the supply, export, and the prices of supply. The first two are forecasted to multiply by a factor of 2.5 and 14.5. The latter is projected to decrease by 24%.

Supply derived from the commercial forest plantations (S^{MWfprw}) would grow 3.5 times while the one derived from natural forest (S^{MWnfrw}) would decrease by 20%. For the years 2022, 2030 and 2038, S^{MWfprw} would reach 1,150 2015tmCOP (62% of the S^{MWrw}), 2,811 2015tmCOP (80% of the S^{MWrw}) and 5,871 2015tmCOP (91% of the S^{MWrw}), respectively. By the last year of the period of simulation (2047), this supply would hit a record of 10,131 2015tmCOP (96% of the S^{MWrw}), which is around 10 times its value of the first year of the period of simulation (2021).

Regarding the exports of MWrw (X^{Mwrw}), its growth throughout the period 2021-2047 will solely rely on the wood sourced from PFCm, as Colombia has a ban on exports of unprocessed wood sourced from the natural forest. For S4, the pace at which X^{Mwrw} will increase would be steady. Compared to its 2019 level (50 2015tmCOP), in S4, X^{Mwrw} will multiply by 4.5, 41, 106, and 198 times by 2022, 2030, 2038 and 2047, respectively. Hence, they will reach 178, 1,674, 4,374, and 8,129 2015tmCOP for each of those years.

With respect to the PS^{MWrw}, the decrease of 24% would happen gradually due to the fact that VAS of S1 and S4 are pretty much the same in the first years of simulation, as the new plantations reach the stage of thinnings. From 2021 to the end year of the second period of the PFCm implementation (2030), in S4, the PS^{MWrw} would fall gradually each year, by less than 10% annually (compared to the PS^{MWrw} of S1). In 2031, the PS^{MWrw} would begin to fall more rapidly but steadily, and the drop will jump from 11% in that year to 29% in 2038. PS^{MWrw} would continue to fall by higher rates each year, until 2047, when it would be 56% percent less than the one in S1.

As stated at the beginning of this subsection, results for S2, S3, S5 and S5, are not discussed here but are instead summarized in Table 7-9 in a comparative manner, which gives the reader a complete and synthesized view of the impacts of the changes in VAS in each of the endogenous variables of the CFSM-I. This is achieved by using the average values of each scenario, and the change factor of rise or decline of the values of the variables of scenarios S2 to S6, with respect to their values under S1.

Table 7-9 Averages and factor of increase/decrease of key variables of Colombia's wood forest products markets under six scenarios of commercial forest plantation (PS, PC, PM, PX in deflators 2015 = 1, all variables in 2015 thousand million COP)

Scenarios	S1 (Base scenario)	S2		S3		S4		S5		S6	
Variable	Average	Average	Change factor	Average	Change factor	Average	Change factor	Average	Change factor	Average	Change factor
S^{MWfprw}	1 383	2 392	1.73	2 580	1.87	4 733	3.42	5 688	4.11	1 568	1.13
S^{MWnfrw}	797	748	0.94	740	0.93	636	0.80	590	0.74	788	0.99
C^{MWrw}	1 945	1 961	1.01	1 963	1.01	1 994	1.03	2 008	1.03	1 948	1.00
X^{MWrw}	234	1 179	5.03	1 355	5.78	3 366	14.37	4 260	18.19	404	1.73
M^{MWrw}											
PC^{MWrw}	1.44	1.34	0.93	1.32	0.91	1.09	0.76	0.99	0.69	1.42	0.99
PX^{MWrw}	1.50	1.50	1.00	1.50	1.00	1.50	1.00	1.50	1.00	1.50	1.00
PM^{MWrw}	0.79	0.79	1.00	0.79	1.00	0.79	1.00	0.79	1.00	0.79	1.00
PS^{MWrw}	1.44	1.34	0.93	1.32	0.92	1.10	0.76	1.00	0.69	1.42	0.99
S^{w}	4 621	4 624	1.00	4 625	1.00	4 632	1.00	4 635	1.00	4 622	1.00
C^{w}	7 573	7 574	1.00	7 574	1.00	7 574	1.00	7 575	1.00	7 573	1.00
X^{w}	139	139	1.00	139	1.00	139	1.00	139	1.00	139	1.00
M^{w}	3 106	3 099	1.00	3 102	1.00	3 085	0.99	3 083	0.99	3 099	1.00
PC^{w}	1.81	1.81	1.00	1.81	1.00	1.81	1.00	1.81	1.00	1.81	1.00
PX^{w}	1.48	1.48	1.00	1.48	1.00	1.48	1.00	1.48	1.00	1.48	1.00
PM^{w}	1.21	1.21	1.00	1.21	1.00	1.21	1.00	1.21	1.00	1.21	1.00
PS^{w}	1.81	1.81	1.00	1.81	1.00	1.81	1.00	1.81	1.00	1.81	1.00
S^{f}	8 989	9 003	1.00	9 006	1.00	9 035	1.01	9 048	1.01	8 992	1.00
C^{f}	11 149	11 150	1.00	11 150	1.00	11 152	1.00	11 153	1.00	11 149	1.00
X^{f}	425	425	1.00	425	1.00	425	1.00	425	1.00	425	1.00
M^{f}	2 583	2 573	1.00	2 572	1.00	2 537	0.98	2 526	0.98	2 572	1.00
PC^{f}	1.56	1.56	1.00	1.56	1.00	1.56	1.00	1.56	1.00	1.56	1.00
PX^{f}	1.58	1.58	1.00	1.58	1.00	1.58	1.00	1.58	1.00	1.58	1.00
PM^{f}	1.31	1.31	1.00	1.31	1.00	1.31	1.00	1.31	1.00	1.31	1.00
PS^{f}	1.56	1.56	1.00	1.56	1.00	1.56	1.00	1.56	1.00	1.56	1.00
S^{z}	17 134	17 195	1.00	17 203	1.00	17 326	1.01	17 379	1.01	17 147	1.00
C^{z}	23 668	23 692	1.00	23 694	1.00	23 741	1.00	23 761	1.00	23 673	1.00
X^{z}	1 394	1 394	1.00	1 394	1.00	1 394	1.00	1 394	1.00	1 394	1.00
M^{z}	7 886	7 868	1.00	7 846	0.99	7 781	0.99	7 760	0.98	7 905	1.00
PC^{z}	1.40	1.39	1.00	1.39	0.99	1.38	0.98	1.37	0.98	1.40	1.00
PX^{z}	1.26	1.26	1.00	1.26	1.00	1.26	1.00	1.26	1.00	1.26	1.00
PM^{z}	1.19	1.19	1.00	1.19	1.00	1.19	1.00	1.19	1.00	1.19	1.00
PS^{z}	1.39	1.39	1.00	1.39	0.99	1.37	0.99	1.37	0.98	1.39	1.00

7.3.2 Simulations for Category II of policy experiments

The 2021-2047 forecasted monetary values of S, C, X, M and their deflator prices PS, PC, PM, PX for the MWrw, w, f, and z Colombian markets, under the alternative policy scenarios of Colombia´s manufactured wood forest products industry expansion are presented in Figures 7-7 to 7-10. The forecasted values, obtained for the market clearing situation in all four markets connected, are organized by expansion scenario of forest plantation area, S2 to S5, as simulations for Category II of policy experiments use the output of simulations of Category I. As in category I , the base scenario is S1, discussed in the preceding subsection.

Similarly to Figures 7-1 to 7-6, Figures 7-7 to 7-10 include the actual data from 1975 to 2020 in each of panels of every scenario for comparison. The same restrictions imposed on the CFSM-I for the simulations to produce the forecast for Category I were also used in producing the forecast of Category II. For simulations of category II, not only VAS (and consequently VAST) is different for S2 to S5, but also Labor (L) and Capital (K). However, the magnitude and duration of the shock on L and K that represents the 2023-2038 expected expansion of production capacity (EEPC) for the Colombian wood forest products industry is the same for each of the four scenarios modelled (S2 to S5). The EEPC, measured by the expansion factor of the current (2020) capacity production, is 5.3 for the wood industry (w), 4.9 for the (wooden) furniture industry (f), and 6.0 for the pulp & paper industry (z).

In the same fashion as the experiments for Category I, a table that summarizes the average and change factor for each of the forecasted variables has been prepared, and it is presented at the end of this subsection. However, the discussion is concentrated solely on the impacts of the changes of L and K on the Consumption (C) and Imports (M), as outlined in the fourth objective of this research. An extract of the mentioned table that shows only the levels C and M and their corresponding PC and PM is presented in table 7-10.

Table 7-10 2021-2047 averages and change factor for C, M, PC and PM for wood forest products under four scenarios of commercial forest plantations, and an expansion of the manufactured wood products industry in Colombia (2015 = 1 for PC and PM, 2015 thousand million COP for C and M)

Scenarios	S1 (Base scenario)	S2		S3		S4		S5	
Variable	Average	Average	Change factor	Average	Change factor	Average	Change factor	Average	Change factor
C^{MWrw}	1 945	2 047	1.05	2 049	1.05	2 081	1.07	2 095	1.08
PC^{MWrw}	1.44	1.34	0.93	1.32	0.91	1.09	0.76	0.99	0.69
PM^{MWrw}	0.79	0.79	1.00	0.79	1.00	0.79	1.00	0.79	1.00
C^{w}	7 573	7 577	1.00	7 577	1.00	7 578	1.00	7 578	1.00
M^{w}	3 106	3 061	0.99	3 060	0.99	3 058	0.98	3 041	0.98
PC^{w}	1.81	1.81	1.00	1.81	1.00	1.80	1.00	1.80	1.00
PM^{w}	1.21	1.21	1.00	1.21	1.00	1.21	1.00	1.21	1.00
C^{f}	11 149	11 224	1.01	11 224	1.01	11 226	1.01	11 227	1.01
M^{f}	2 583	1 711	0.66	1 704	0.66	1 681	0.65	1 662	0.64
PC^{f}	1.56	1.46	0.94	1.46	0.94	1.46	0.93	1.46	0.93
PM^{f}	1.31	1.31	1.00	1.31	1.00	1.31	1.00	1.31	1.00
C^{z}	23 668	24 911	1.05	24 913	1.05	24 960	1.05	24 980	1.06
M^{z}	7 886	5 964	0.76	5 941	0.75	5 845	0.74	5 824	0.74
PC^{z}	1.40	1.05	0.75	1.05	0.75	1.03	0.74	1.03	0.73
PM^{z}	1.19	1.19	1.00	1.19	1.00	1.19	1.00	1.19	1.00

Regarding consumption, the expected 2023-2038 increase in Colombia's capacity production of the manufactured wood products industry by 5.5 times its 2020 level would generate, on average, small increases in the consumption of MWrw, z and f during 2021-2047, for all scenarios compared to S1. The highest increases would concentrate in C^{MWrw} and C^{z} (5% to 8% for all scenarios), a negligible rise is forecasted for C^{f} (1%), while no increase is projected for C^{w}.

It is important to note that forecasted rises for each variable (e.g. C^{MWrw}) under S2 to S4 are quite small, which might indicate that the difference in area (that is translated into VAS) for these four scenarios does not matter. However, for a definitive conclusion, figures in Table 7-10 should be interpreted jointly with their corresponding annual values presented in levels in Figures 7-7 to 7-10, or in annual percentages of change from S1 to each of the scenarios modelled in Appendix 7-2. From an analysis of Figures 7-7 to 7-10, Figures 7-2 to 7-5, and the data on the Appendix 7-2, one can confirm that for C of MWrw and w, the differences in VAS would not matter importantly if compared with the base scenario S1.

A different conclusion can be reached it the forecast analyzed is that of imports. Table 7-10 shows that, for S2 to S4, if the production capacity of the manufactured wood products is multiplied by

5.5 times during the next 15 years, imports of f and z would reduce by around 35% for the former and by 25% for the latter in the succeeding 25 years, in all four scenarios, compared to the imports of the base scenario. As in consumption, averages figures on Table 7-10 seem to indicate that differences in VAS for S2, S3, S4 and S5 would not matter. A more detailed analysis of Figures 7-7 and 7-2, and the annual data on Appendix 7-2, shows that this is certainly true, and that for imports, as expected, what matters is the production capacity. Under S4, if Colombia expands its capacity following the guidelines of its PFCm policy, its imports will plummet in 2026 for z and in 2024 for f. From then on, the fall would oscillate annually between 15% to 52% of the value of M^f in S1, while the drop of M^z would range annually from 21% to 47% of their annual values on S1.

Two last things are worth mentioning. First, in Table 7-10, imports of w seem to not be affected by the increase of capacity for that industry. Annual data confirms that the decrease in M^w is quite low in all scenarios, and, in S4, it would not surpass 3% in any of the years of the simulation. Second, other endogenous variables are significantly affected by the expansion of the production capacity, as shown in table 7-11. Both are interesting subjects to explain but they are left for future research.

Table 7-11 2021-2047 averages and change factor for all endogenous variables of the CFSM-I for wood forest products under four scenarios of commercial forest plantations, and an expansion of the manufactured wood products industry in Colombia (2015 = 1 for price deflators, 2015 thousand million COP for all other variables)

Scenarios	S1	S2		S3		S4		S5	
Variable	Average	Average	Change factor	Average	Change factor	Average	Change factor	Average	Change factor
S^{MWfprw}	1 383	2 392	1.73	2 580	1.87	4 733	3.42	5 688	4.11
S^{MWnfrw}	797	748	0.94	740	0.93	636	0.80	590	0.74
C^{MWrw}	1 945	2 047	1.05	2 049	1.05	2 081	1.07	2 095	1.08
X^{MWrw}	234	1 094	4.67	1 271	5.43	3 286	14.03	4 169	17.80
M^{MWrw}									
PC^{MWrw}	1.44	1.34	0.93	1.32	0.91	1.09	0.76	0.99	0.69
PX^{MWrw}	1.50	1.50	1.00	1.50	1.00	1.50	1.00	1.50	1.00
PM^{MWrw}	0.79	0.79	1.00	0.79	1.00	0.79	1.00	0.79	1.00
PS^{MWrw}	1.44	1.34	0.93	1.32	0.92	1.10	0.76	1.00	0.69
S^{w}	4 621	4 660	1.01	4 660	1.01	4 667	1.01	4 670	1.01
C^{w}	7 573	7 577	1.00	7 577	1.00	7 578	1.00	7 578	1.00
X^{w}	139	139	1.00	139	1.00	139	1.00	139	1.00
M^{w}	3 106	3 061	0.99	3 060	0.99	3 058	0.98	3 041	0.98
PC^{w}	1.81	1.81	1.00	1.81	1.00	1.80	1.00	1.80	1.00
PX^{w}	1.48	1.48	1.00	1.48	1.00	1.48	1.00	1.48	1.00
PM^{w}	1.21	1.21	1.00	1.21	1.00	1.21	1.00	1.21	1.00
PS^{w}	1.81	1.81	1.00	1.81	1.00	1.80	1.00	1.80	1.00
S^{f}	8 989	9 947	1.11	9 949	1.11	9 979	1.11	9 992	1.11
C^{f}	11 149	11 224	1.01	11 224	1.01	11 226	1.01	11 227	1.01
X^{f}	425	425	1.00	425	1.00	425	1.00	425	1.00
M^{f}	2 583	1 711	0.66	1 704	0.66	1 681	0.65	1 662	0.64
PC^{f}	1.56	1.46	0.94	1.46	0.94	1.46	0.93	1.46	0.93
PX^{f}	1.58	1.58	1.00	1.58	1.00	1.58	1.00	1.58	1.00
PM^{f}	1.31	1.31	1.00	1.31	1.00	1.31	1.00	1.31	1.00
PS^{f}	1.56	1.46	0.94	1.46	0.94	1.46	0.93	1.46	0.93
S^{z}	17 134	20 323	1.19	20 331	1.19	20 454	1.19	20 508	1.20
C^{z}	23 668	24 911	1.05	24 913	1.05	24 960	1.05	24 980	1.06
X^{z}	1 394	1 394	1.00	1 394	1.00	1 394	1.00	1 394	1.00
M^{z}	7 886	5 964	0.76	5 941	0.75	5 845	0.74	5 824	0.74
PC^{z}	1.40	1.05	0.75	1.05	0.75	1.03	0.74	1.03	0.73
PX^{z}	1.26	1.26	1.00	1.26	1.00	1.26	1.00	1.26	1.00
PM^{z}	1.19	1.19	1.00	1.19	1.00	1.19	1.00	1.19	1.00
PS^{z}	1.39	1.05	0.75	1.05	0.75	1.03	0.74	1.03	0.74

Figure 7-7 2021-2047 forecasted values for supply, Consumption, Exports and Import and their prices for the Colombian wood forest products markets under scenario S4 (1.5 Mha Colombia's commercial plantations, to be reached in 2025, maintained to perpetuity) and an expansion of the manufactured wood products industry in Colombia – Category II of Policy Experiments

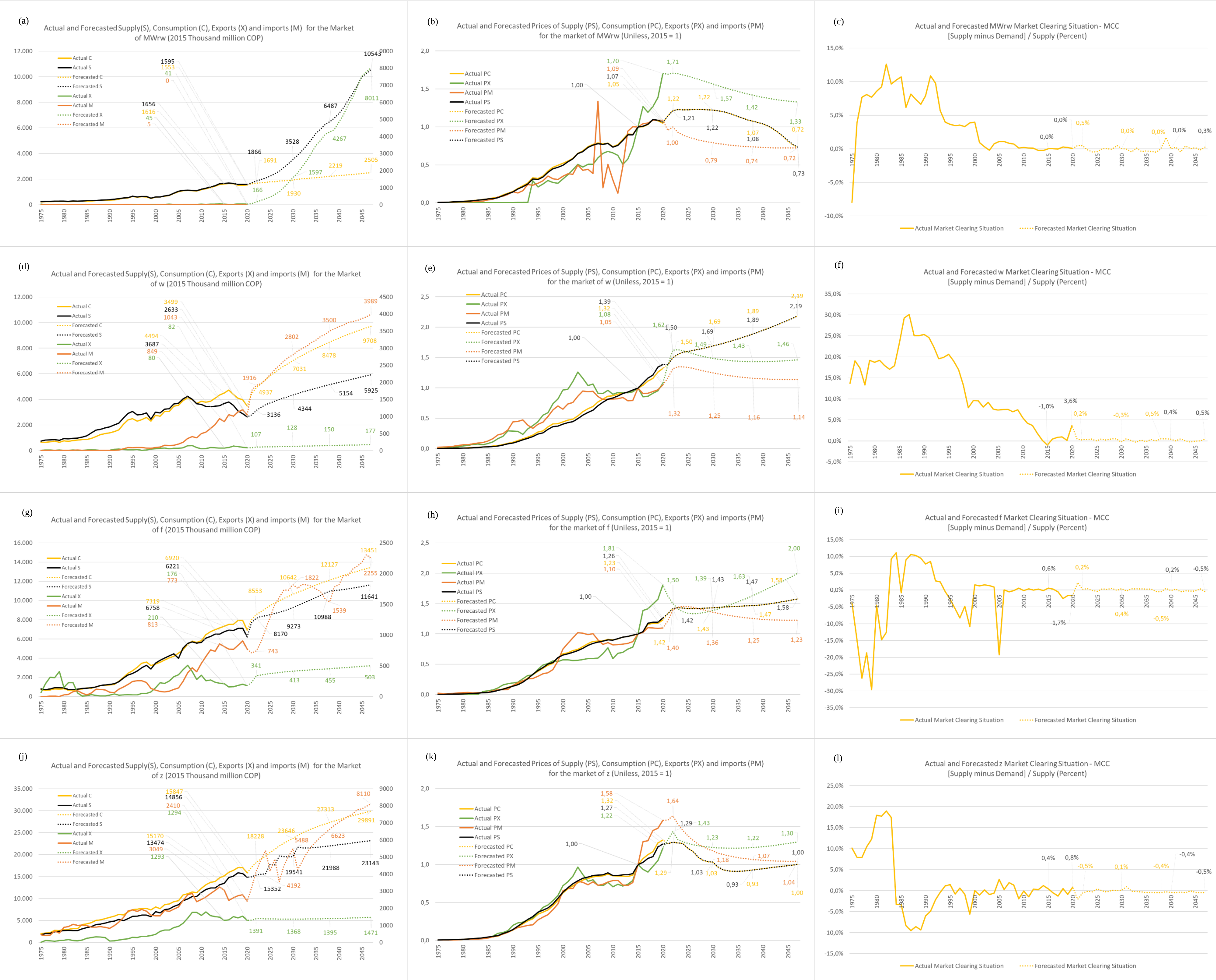


Figure 7-8 2021-2047 forecasted values for supply, Consumption, Exports and Import and their prices for the Colombian wood forest products markets under scenario S2 (0.45 Mha Colombia's commercial plantations maintained to perpetuity) and an expansion of the manufactured wood products industry in Colombia – Category II of Policy Experiments

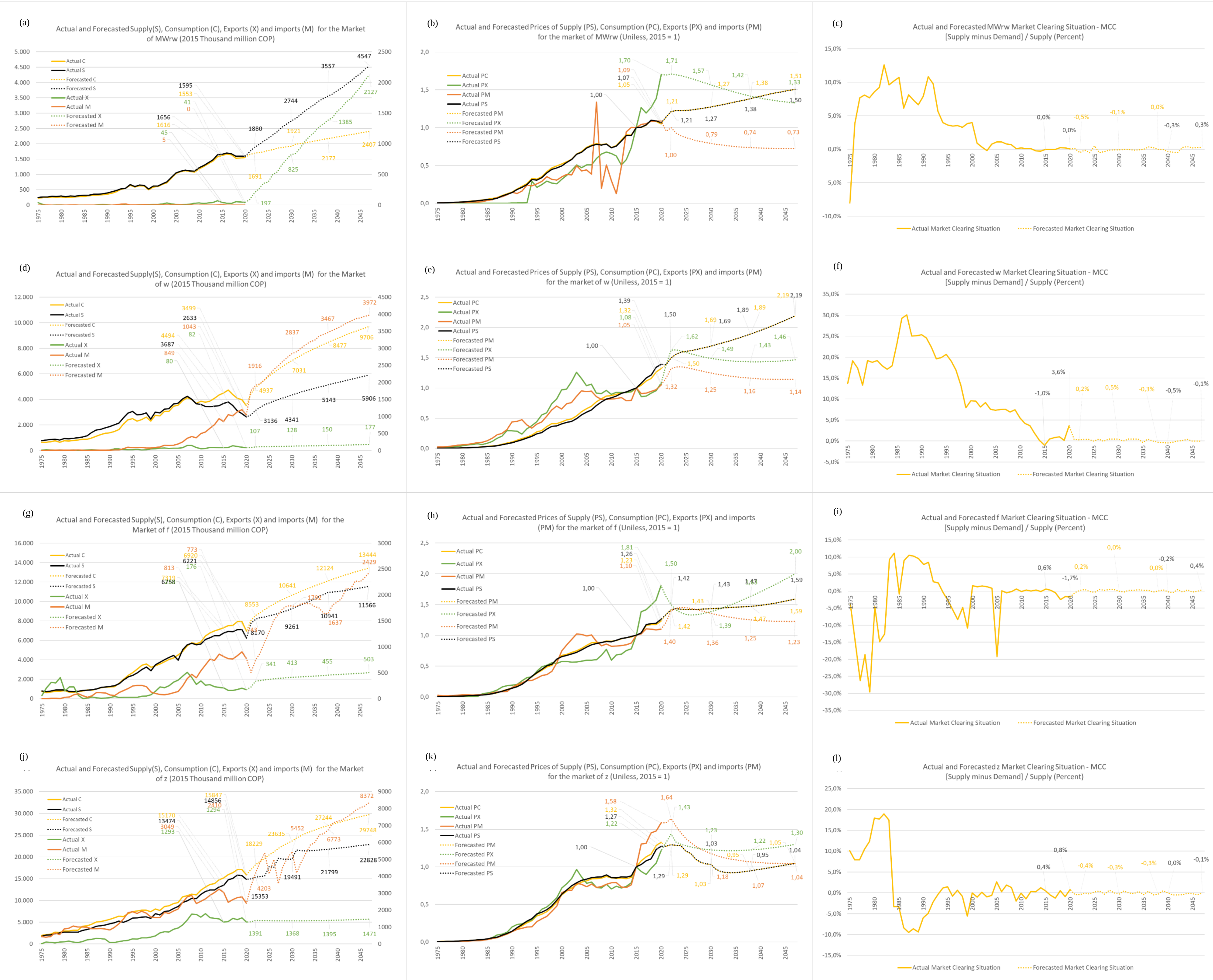


Figure 7-9 2021-2047 forecasted values for supply, Consumption, Exports and Import and their prices for the Colombian wood forest products markets under scenario S3 (0.765 Mha Colombia's commercial plantations, to be reached in 2035, maintained to perpetuity) and an expansion of the manufactured wood products industry in Colombia – Category II of Policy Experiments

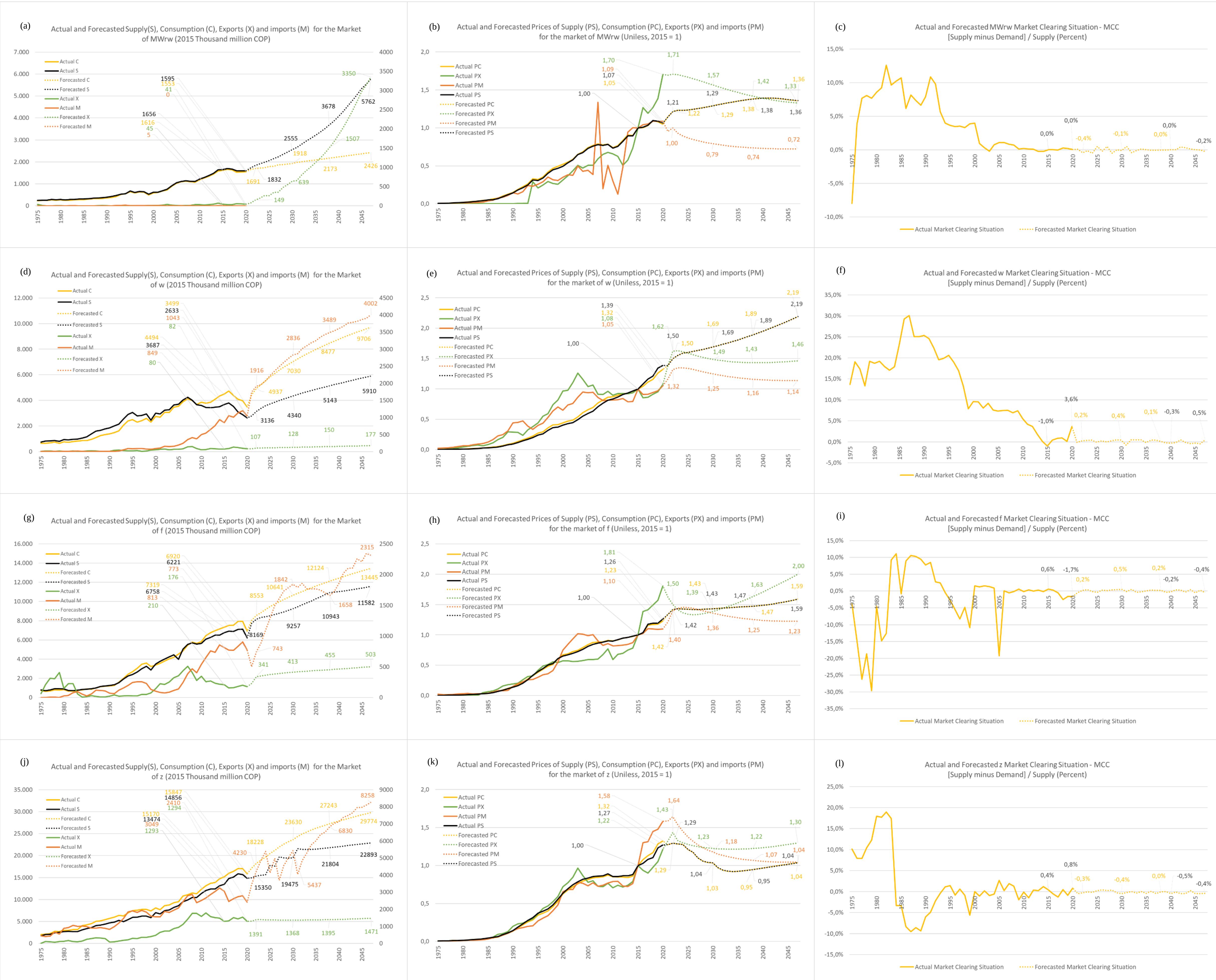
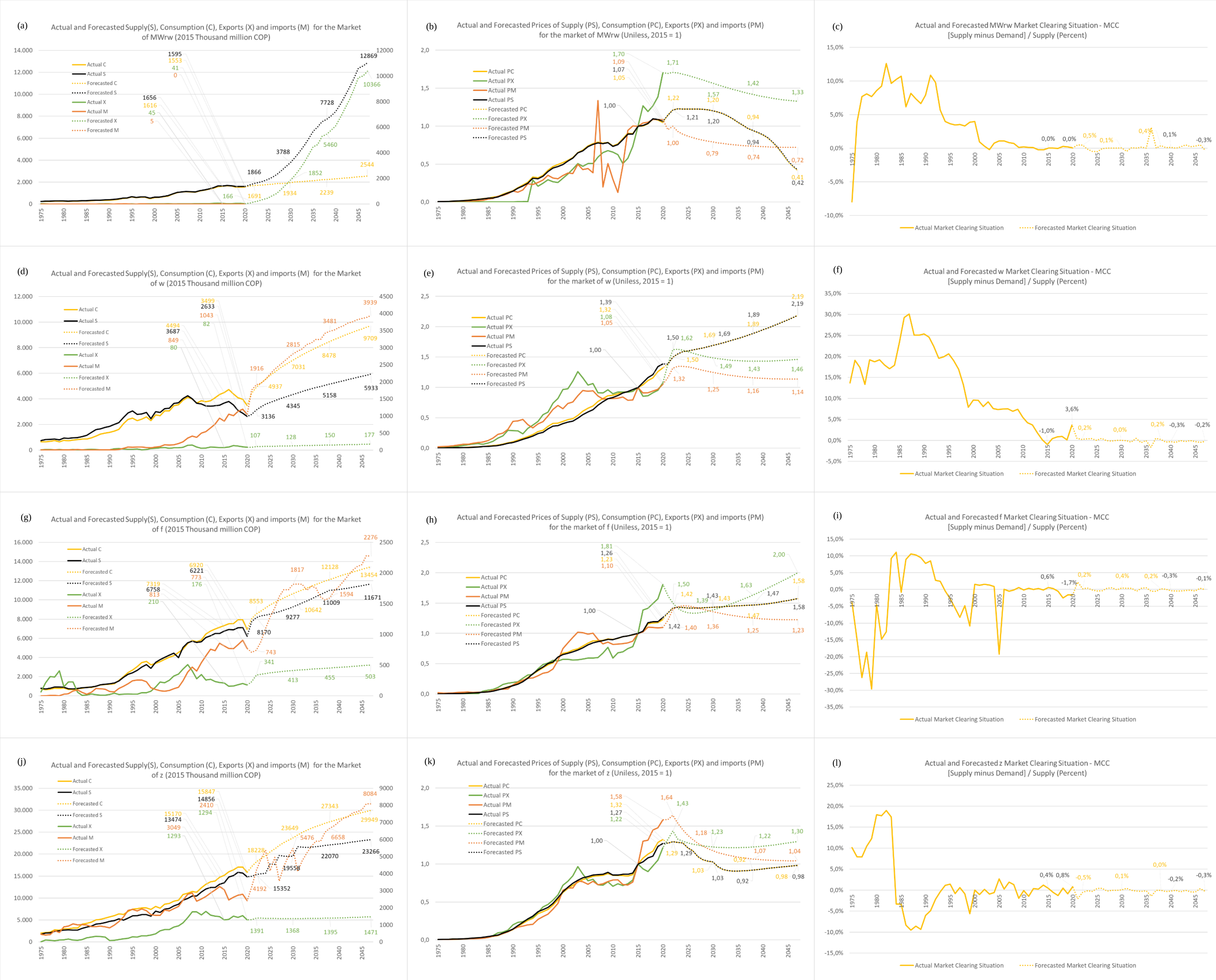


Figure 7-10 2021-2047 forecasted values for supply, Consumption, Exports and Import and their prices for the Colombian wood forest products markets under scenario S5 (2.0 Mha Colombia's commercial plantations, to be reached in 2025, maintained to perpetuity) and an expansion of the manufactured wood products industry in Colombia – Category II of Policy Experiments



Chapter 8
Conclusions

Since the 1980s, forest sector models (FSMs) have been used in providing useful analytical inputs for forest policy design and analysis, and examination of other aspects of the forest sector. Specific applications, where outputs provided by a FSM have been key, range from explaining and forecasting the forest sector development to understanding the role of forests in climate change. Scientific literature reports the development of FSMs and their applications at the global, regional, and national frameworks. In the latter framework, however, these studies have been completely focused on the temperate regions of the world.

Tropical countries, where the forest sector is usually poorly understood, have been completely absent of the advances in this research field and its literature. Lack of country-specific data demanded for building a FSM, e.g., prices, has been argued to be the reason for some researchers not to commit to building FSMs for those countries. This preconception may have come from the fact that researchers expect to find, in the tropical countries, information for the forest sector similar to that available in temperate countries, usually collected by the National Forest Service, such as long time-series for prices of stumpage, logs, sawnwood, etc., or studies revealing the elasticities of the country´s forest sector. In tropical countries, this sectoral information is usually not readily available, but it can be derived especially from the country's National Accounts and other national sources of information available for the forest sector, which have been scantily exploited.

This research addressed the gap in the research field and the scientific literature by focusing on building from scratch a FSM for a tropical country, Colombia, and using it for analyzing both its forest sector development and forest policy. In doing that, theoretical, methodological, and policy contributions were made. Some of the contributions, specially those related to policy, apply strictly to Colombia while others are relevant to tropical developing countries in general and at global scale.

Theoretical and methodological contributions

In building the Colombian Forest Sector Model (CFSM), this research contributes to the expansion of a modeling approach for the forest sector marginally used in forest economic research since the Lucas Critique (1976): the use of structural econometric partial equilibrium (SEPE) models. The latest report about SEPEs found in forest economics scientific literature corresponds to Kant et al. (1996), in the modeling of the Canadian manufactured wood forest product sector. This research expands the approach of Kant et al. for building a SEPE in order to model a complete forest sector in tropical countries. The theoretical and methodological approach of the CFSM serves as a framework for developing a FSM in any tropical country, and could also be used to improve some of the existing FSMs in the temperate world.

Under this research the CFSM has been set up completely from the theoretical and conceptual points of view. It uses the neoclassical theory of competitive markets to find the equilibrium quantities and prices of Supply, Consumption, Exports, and Imports of the forest markets in Colombia. The model maps the two aggregated markets that make up the forest sector: the unprocessed forest products market and the manufactured forest products market. Both aggregated markets include two (sub)aggregated markets: wood goods and non-wood goods. The unprocessed forest products market also includes the (sub)aggregated market for forest ecosystem services. Each of the “individual” markets making up any of these three (sub)aggregate markets is represented by a SEPE model, comprising behavioral equations that explain Supply, Consumption, Exports, and Imports, and the prices of the last three. Supply price is found using the identity for the market clearing condition, i.e., Supply = Demand, where demand is defined as consumption plus exports minus imports.

As the individual markets of the forest sector are intrinsically linked to the national sources of unprocessed forest products, in addition to the market models, the CFSM incorporates several simulators for the behavior of these sources. The simulators mimic the area and yield dynamic of Colombia’s planted forest, natural forests, agroforestry systems, and trees outside forests. The physical quantities of national unprocessed forest products available to supply the markets are modeled through the CFSM simulators. The interfaces between the CFSM individual market models and simulators complete the picture of the Colombian forest sector's natural, technological, and economic facts and interactions.

Usually, building large-scale models, such as the CFSM, is not an easy task and takes quite some effort and time. The best way to undertake the task is in phases. This strategy was used for constructing the CFSM, dividing it into two phases. Phase I of the CFSM (CFSM-I), developed in detail under this research, has included only the wood forest products and the development of the Colombian Forest Plantation Growth and Yield Simulator (SCRPFC). All aspects of the non-wood forest products and forest ecosystem services markets as well as the simulators for the natural forest, agroforestry systems, and trees outside forests (i.e., CFSM-II) were left for future research.

The CFSM-I uses two (sub)models: the Unprocessed or raw wood products model (UWM) and the Manufactured wood products one (MWM). The UWM models the sum of two individual markets: Unprocessed wood for manufactured wood products industry & final use other than firewood (MWrw) and Unprocessed wood for firewood (FWrw). The MWM models the aggregation of three individual markets: manufactured products of the wood industry (w), manufactured products of the furniture industry (f), and manufactured products of the pulp & paper industry (z). Each of the five individual markets is represented in the CFSM-I by a SEPE model.

In its Phase I (i.e., CFSM-I), the CFSM is able to provide useful analytical information for stakeholders to back up their analysis of forest policy, and other aspects of the Colombian forest sector. Types of analysis that can be supported with the CFSM-I are mainly those of the wood forest products market, manufactured wood forest product industry, commercial forest plantations, and natural forests. Analytical information related to Colombia’s natural forest is restricted in the CFSM-I, as it lacks a simulator for the natural forest (which is part of the CFSM-II). However, the current stage of the model allows for experiments related to implications of changing the size of the volume of wood harvested in this source, which was not possible prior to the CFSM-I.

Once the CFSM-II is developed, the CFSM will be able to provide a more complete analytical picture of the Colombian forest sector. In addition to being able to deliver more specific information about the wood forest products sourced in Colombia's natural forest, agroforestry systems, and trees outside forests, the CFSM will offer analytical information for studying other topics related to the forest ecosystem services, non-wood forest products, forest restoration, biodiversity conservation, the role of forest in the global climate crisis, and other ecological issues.

The CFSM has also been designed and built with the capacity to be embedded into a GE model of the Colombian economy, making it an even more powerful tool in assisting Colombia's stakeholders in more complex analyses of the ecological, economic and social impacts of the policies and decisions made in the forest sector, other sectors, and nationwide. A simple example of these analyses is providing answers to questions such as: what is the impact of the forest policy on other sectors and the total Colombian economy and welfare? and, what effects can the Colombian forest sector be expected to experience from changes in other sectors and macroeconomic policies implemented in the country? The methodology for embedding the sectoral model in a GE model was already proposed by Kant et al. (1996), however the linking of SEPE and GE models has been barely explored for analyzing forest sector issues. The connection between the CFSM and a Colombian GE model is, without doubt, part of the further research than can be carried out.

Almost all information needed for estimating the behavioral equations for each of the five individual markets modeled under the CFSM-I was sourced from the National Accounts of Colombia. Consolidated time series for the country's forest sector covered between six and eight decades. This confirmed the hypothesis of this research that the availability of the country's specific information for the forest sector, including that of prices of forest products, is not a real issue in tropical countries to build and use FSMs. As has been the case with Colombia for several decades, most tropical countries have implemented their National Accounts Systems following the United Nations standard, which includes statistics for the forest sector separated from other economic sectors, meaning that the data for constructing country-specific FSMs is already available.

What might be an issue in a tropical country is the interest, involvement, time, patience, and basic knowledge required to search for, collect, organize and consolidate the information demanded for building a FSM. The example of Colombia might be the case for most tropical countries. In this country, forest sector information was scattered throughout multiple sources, mostly in a printed paper format (some of them yet to be published), owned and administrated by several organizations or even individuals, and the public information is not kept in information systems like those existing in temperate countries, e.g., Statistics Canada. In any tropical country, this panorama of the sectoral information would result in seeing just the collection of data as a cumbersome task, even if the modelers knew the basics for facing and solving all the difficulties to achieve the consolidation of data.

Usually, data consolidation has received minor attention in publications about FSMs. However, for tropical countries like Colombia, where researchers and practitioners qualified in the field of forest economics and modeling are just a handful, this subject is relevant. This research has shown in detail what sources to look for, in what way to manage the information found, and how to deal with the usual difficulties of achieving the consolidation of time series needed to estimate the behavioral equations of a partial equilibrium structural econometric model of the forest sector in tropical settings. The Colombian Forest Sector Database (CFS-DB) developed in this research synthetizes all the work done for data consolidation and, as a byproduct, showed how to organize the information collected and to avoid the lack of transparency resulting from the high complexity of FSMs, the latter an issue already reported for some scholars (Toppinen & Kuuluvainen 2010).

The data consolidation process carried out under this research also allowed to address several important issues regarding the quality, availability, accessibility, and dissemination of information about the Colombian forest sector. This exhaustive route can be followed for any other tropical country. From now on, Colombia counts with comprehensive databases on its forest sector and a path for researchers and practitioners to continue working on this endeavor, using the technological advances and the recently renovated interest of its public institutions in having the current forest information collected, processed, and disseminated. Complete databases for Colombian commercial forest plantations since their inception in the 1950s, annual harvested volumes since 1970, including estimations of illegal wood, and the evolution and statistics of the forest sector as measured in the National Accounts of Colombia are three of the outstanding contributions of this research to improving the dissemination of good quality and accessible information for the country's forest sector.

Also, the work done with data under the framework of this research expanded to demonstrate how to use the consolidated data to better understand the development of the forest sector in Colombia. Statistical indicators for key variables of the Colombian forest sector consolidated in this research, e.g., volumes of the available stock of wood in forest plantations, volumes harvested in the natural and planted forests, supply of wood forest products and their demand, exports, imports, and prices, jointly with other sources of information of the CFS-DB have been used in explaining the Colombian forest sector development since its inception. The complete analysis of the Colombian wood forest products market and the market of manufactured wood products of the wood industry are two examples of it. Both analyses are just a preamble for new modelers, for tropical settings, in how to enrich their understanding of the target being modeled under a FSM before embarking on the task of the model estimation. Completing the analysis of the Colombian market of manufactured wood products of the pulp & paper and furniture industry, as well as those for the unprocessed wood for manufactured wood products industry & final use other than firewood and unprocessed wood for firewood, for which all the information was consolidated and prepared in this thesis, are part of the future research.

Incidentally, in building the CFSM-I, this research produced new forest economic information for Colombia: 32 behavioral equations and 86 elasticities estimates of supply, consumption, exports, imports, and prices of consumption, imports, and exports. These equations and elasticities can be used in isolation for various purposes, including policy design and analysis, private decision-making, and research. For research, it covers modeling of the forest sector by using theoretical approaches different than that used for the CFSM. This new information would not only benefit Colombia, but also the global institutions (e.g. ITTO and FAO) and other researchers trying to better understand and analyze the forest sector in the tropics.

Recommendations for Policy Makers and other Stakeholders of Colombia's Forest Sector

The ultimate incentive of building the CFSM-I was to use it to analyze the impacts of Colombia's 2018-2038 forest plantation policy for wood production value chain (PFCm policy), officially issued in June 2019, and provide recommendations for policy makers and other stakeholders of the Colombian forest sector (CFS). In this regard, contributions of this research are limited to two aspects of the PFCm policy, the expansion of both Colombia's commercial forest plantations and the production capacity of its manufactured wood forest products industry.

For the first aspect of the PFCm policy, only one component of the CFSM-I was used (the SCRPFC[80]) to provide policy makers and other stakeholders with a more precise framework, in physical terms, for adequate discussion and action during the evaluation stage of the policy, whose first exercise will be conducted in 2023. By using the SCRPFC, the 2015-2047 expected volume of wood for different industrial use, sourced from the current (2015)[81] and the expanded areas of Colombia's PFCm expected to reach, by 2025, 1.5 Mha under sustainable management (the goal of the PFCm policy) was estimated. These results were compared with to the SCRPFC output of five other alternative policies of scenario expansion of commercial forest plantations (0.3 Mha, 0.45 Mha, 0.765 Mha and 2.0 Mha under sustainable rotation, and 0.3 Mha harvested without replanting). The first two of these scenarios are alternative figures of the existing area on Dec 31 of 2015. The third and fourth scenarios are alternative goals to the 1.5 Mha, expected to be achieved by 2035 and 2025, respectively.

As such, efforts and contributions of this research concentrated in illustrating the annual availability of wood in Colombia's PFCm and in discussing its implications (impacts) for the wood supply to its forest industry. If by 2025 Colombia reaches and sustainably manages 1.5 Mha of PFCm, the country will count, on average, with 26 Mm^3rsc/year once this forest mass achieves the stage of a normal forest (20.8 Mm^3rsc/year for the period 2015-2047 without operating as a normal

[80] Colombian Forest Plantation Growth and Yield Simulator (SCRPFC, by its acronym in Spanish)

[81] 0.3 million ha (Mha)

forest). In the succeeding 25 years, this volume would allow for expansion of the: (a) sawnwood industry by three to four times its current (2022) production capacity currently estimated at 3.0 Mm^3rsc/year, (b) CIPTPI (group of industries of pulp, wood-based panels (boards), and innovative manufactured wood forest products, by its acronym in Spanish) by five to six times its current production capacity, estimated at 1.8 Mm^3rsc/year for 2022.

The increasing forecasted availability of wood from PFCm for the period 2015-2047 indicated that the mentioned expansion can be achieved during the second (2023-2030) and third (2031-2038) periods of implementation of the PFCm policy, as follows: an increase to 6 Mm^3rsc/year for the sawnwood industry and 9 Mm^3rsc/year for the CIPTPI for the former period, and an increase to 9 Mm^3rsc/year for the sawnwood industry and 11 Mm^3rsc/year for the CIPTPI for the latter one. These industry expansions will not only allow to Colombia to meet its increasing domestic consumption of wood forest products for the next 3 decades, but also become the third producer and exporter of wood forest products of South America, after Brazil and Chile, reaching levels of forest development comparable to the latter country.

A strong recommendation for policy makers and other stakeholders is to consider that, according to the simulations of the CFSM-I, taking no action for increasing the current PFCm area (0.3 Mha and 0.45 Mha under sustainable management) or decreasing it (0.3 Mha harvested without replanting), seems not to be an option for Colombia. In addition to continuing in the path of underusing and inadequately utilizing the country's 25 Mha of suitable land for commercial forest plantations, Colombia would carry on deepening its negative trade balance of wood forest products that can be produced competitively in Colombia. It would do so, in order, to meet its future consumption of the manufactured wood primary products (pulp, panels and sawnwood) projected to increase to around 9.2 Mm^3rsc of equivalent wood per year by 2030, and up to 10.6 Mm^3rsc of equivalent wood per year by 2038[82].

[82] 2013- demand for manufactured wood primary products (pulp, panels and sawnwood) was estimated at 5.5 Mm^3rsc of equivalent wood, with only 3% of it corresponding to exports. Estimated data of demand for 2030 and 2038 includes marginal exports of 3%, hence national consumption is approximately equal to Colombia's demand. The estimations for 2030 and 2038 do not include an increase in exports nor the potential domestic demand generated by the implementation of the PFCm policy.

Alternatively, the 0.765 Mha and 2.0 Mha expansion policy scenarios represent additional options for the forest development of Colombia. The difference between these and the 1.5 Mha lies in the available time and the magnitude of the forest development reached by this country.

For the second aspect of the PFCm policy, the complete CFSM-I was used to offer policy makers and other stakeholders complementary information to the physical one, in monetary terms, for the evaluation stage of this policy. By using the CFSM-I, 2021-2047 annual forecasted values were generated for the supply (S), the components of the Demand [consumption (C), exports (X) and imports (M)] [83], and their price deflators PS, PC, PM, and PX for the Colombian markets of z, w, f and MWrw[84].

Two sets of these forecasts were generated. The first set grouped the forecasts for the 1.5 Mha expansion scenario of the current (2020) area of PFCm and its five alternatives expansion scenarios explained above. In obtaining this set of forecasts, the 2015-2047 availability of wood in Colombia's PFCm (VAS) for each scenario expansion, predicted by the SCRPFC, was used as input. The second set clustered the forecasts for the 2023-2038 expected expansion of production capacity (EEPC) for the Colombian wood forest products industry. Measured by the expansion factor of the current (2020) capacity production, this EEPC would multiply it by 5.3 in the wood industry (w), 4.9 in the (wooden) furniture industry (f), and 6.0 in the pulp & paper industry (z).

In this second set of forecasts, the inputs were the values predicted by the CFSM-I in the first set of forecasts, for the 1.5 Mha expansion scenario of the current (2020) area of Colombia's PFCm and four out the five alternatives expansion scenarios[85]. All of the values predicted for S, C, X, M

[83] In the CFSM, Supply (S) is the National Production and the Demand (D) is defined as the sum of Consumption (C) plus Exports (X) minus Imports (M).

[84] Classification w is the group of manufactured wood products of the wood industry, f the group of manufactured products of the furniture industry, z the group of manufactured products of the pulp & paper (z) industries, and MWrw the unprocessed wood for the manufactured wood products industry & for final use other than firewood (MWrw). Note that for the analysis of the PFCm policy, the CFSM-I was simulated without the partial (sub)model representing the market of unprocessed wood for firewood (FWrw).

[85] Scenario of 0.3 Mha harvested without replanting was excluded as this is not a factual scenario for Colombia.

and PS, PM, PX and PM, for all of the four markets (w, f, z, and MWrw) were obtained by simulating the CFSM-I under the market clearing case, without considering the unprocessed wood for firewood market, and restricting the price of consumption to be equal to PS in all markets. Also, in both sets of forecasts, the policy representing 0.3 Mha of forest plantations maintained to perpetuity served as base scenario.

Measured in monetary terms, increasing Colombia's commercial forest plantations to 1.5 Mha by 2025, around five times its area at December 2015 or three times its area at December 2021, would have a pronounced impact on the market of unprocessed wood, and it would marginally affect the markets of manufactured wood products of the furniture and pulp & paper industry.

Comparatively with the base scenario, all else equal, the 2021-2047 five-time increase of the volume available for supply in the forest plantations (i.e., 625 Mm^3rsc), would cause the supply and exports of MWrw to multiply by 2.5 and 14.5 times in the next 25 years, on average. Another monetary impact predicted throughout the years from 2021 to 2047 is that, while the supply from forest plantations would rise by 3.5 times, the supply from the natural forest is forecasted to drop by 20%, on average, compared to the base scenario. In the same period, exports of unprocessed wood would multiply by 15 times, on average, while the larger VAS would make the price of supply drop by an average of 24%, both relative to the base scenario. The impacts, in monetary terms, of the other four alternative scenarios simulated were also substantial in the mentioned variables. Compared to the base scenario, the difference between the impact of the 1.5 Ma and the other scenarios was only on the magnitude of the change.

In regard to the expansion of the Colombian wood forest products industry, the proposed increase (5.5 times, on average, its 2020 levels) would only impact the consumption of unprocessed wood (MWrw) and manufactured wood products of the pulp & paper industry (z), and the imports of z and those of the manufactured products of the furniture industry (f). The impacts on the consumption of MWrw and z for the 0.45 Mha, 0.76 Mha, 1.5 Mha and 2.0 Mha scenarios of commercial forest plantations are represented by a small increase, ranging between 5% to 8%, on average, throughout the course of the next 25 years, always relative to the base scenario. In the same period, imports of z and f would experience a substantial decline, by 35% and 25%, on average, compared to the base scenario. Other endogenous variables of the CFSM were affected by this second experiment, while no effects were noticed on the imports and consumption of the manufactured wood products of the wood industry. This latter finding seems counterintuitive, as an expansion for this industry was included in the experiment. Due to its importance, further analysis on these two topics will be part of future research.

Colombian forest sector policy makers and other stakeholders may keep in mind that the CFSM-I simulation results signal that, augmenting the area of forest plantations for wood production, and increasing the production capacity of the wood forest products industry positively impact different markets of the forest sector. The former has an important impact only on the unprocessed wood market, while the impact of the latter is of importance only in the manufactured wood products markets. This fact, and the results presented in this research could help provide forest stakeholders with the necessary formation, and the backup needed to support their arguments for the PFCm policy evaluation, programmed for 2023, on analytic grounds.

Research limitations, results confidence, and additional supplementary research

In modeling, simplification and compromises are inevitable. In this research, the generalization done in selecting the theoretical framework for the CFSM, and the econometrics and data concessions made in building and using the CFSM-I are testaments to such limitations. They are notable as the results presented in this research may be affected by the above mentioned decisions. However, a careful study of the implications of these decisions on the research results indicate that they are not considerably important, at least not in the first phase of the CFSM (i.e., the CFSM-I).

The theoretical framework

The selection of the theory of competitive markets as the structure to represent the Colombian forest markets in the CFSM-I and CFSM-II is an oversimplification of reality. Hence, conditions necessary to achieve the ideal efficient balance between supply, demand, and prices described and predicted by the selected theory may not hold, partially or entirely, in some or all the forest sector markets modelled under the CFSM. Indeed, market power (e.g. monopoly, oligopoly, monopsony, oligopsony), price-distorted policies, asymmetric information, presence of externalities, weak property rights, and alternative social objectives other than efficiency have been historically affecting the Colombian forest sector and its markets, and may continue to disrupt them in the next decades.

Regarding the CFSM-I, market power may have been (and may continue to be in the future) the main source of market failures in the Colombian aggregated markets of z, w, and Mwrw. In the z and w markets, historically, it could have been some sort of monopoly power, as the national supply markets of pulp and paper & paperboard and wood-based panels have mainly been served by just a handful of suppliers, and the national wood-based panel industry has been subject to protection measures during several periods between 1970-2021, e.g. imports prior licensing regimes and tariffs. Suppliers of Colombian pulp and wood-based panels may also have had some monopsony power in the market of MWrw as they have been, historically, the only buyers of wood of the lowest quality sourced from Colombian forest plantations.

However, the magnitude of these monopoly and monopsony powers so far, and their persistence in the following decades, as well as how much they have affected and may continue to affect the competitive market forces of the Colombian forest markets are issues still pending further investigation.

Colombia's national accounts data and other information consolidated and analyzed under this research provide some initial insight into these matters. The monopoly power in the Colombian market of w and z may have not been, and may not continue to be substantial in the future. Domestic supply and consumption prices for the goods traded in those markets have had and will continue to have an important ceiling corresponding to their respective international prices, due to the reasons outlined below.

Since the 1970s, the w and z markets have become more and more competitive (a similar trajectory for the furniture industry (f), was derived from the data for that market). Also, suppliers of national wood pulp, paper and paperboard, and their derived products (i.e., z products) has never historically met the domestic consumption, and, since the beginning of the 1990s, suppliers of national wood-based panels and sawnwood (both products making up the majority of the w products), have been farther and farther from meeting the domestic consumption of those products.

Currently (October 2022), there are only two suppliers of Colombian pulp (one supplying wood pulp and one supplying sugar cane bagasse pulp), and just two suppliers of wood-based panels (one supplying MDF and MDP, and another supplying only MDP). They have a modest installed production capacity, that has been insufficient in providing from national production the quantities consumed of these products in Colombia, which are expected to significantly increase in the next three decades. In addition, most of the protection of the country's wood-based panel industry has been removed under the Pacto Andino trade agreement, and other trade agreements that Colombia has signed with several countries of America, Europe, and Asia since the second half of the 1990s. Finally, for the subsequent decades, more national producers are expected to participate in the Colombian markets of not only w and z, but also in the f markets.

An increase in the number of national producers in the traditional forest products markets (i.e., in the pulp and wood-based panels markets), and the expected development of Colombia's innovative manufactured wood forest products markets (for forest bioenergy and bio-composites, among others) may result not only in a decreasing effect of the monopoly power of national producers in the market of w and z (if any), but also of their monopsony power in the market of MWrw. This monopsony power could have been important during the 1990s and 2000s, but it has clearly diminished since the 2010s, when the sawn-wood industry started to replace wood sourced in natural forest, used in the production of pallets and other lower quality sawnwood products, with that of low-quality one sourced in forest plantations.

Econometric compromises

In econometric modeling, it is not unusual that, to obtain a complete structural model, the process of selecting the model's final estimated equations must be subject to compromises and, as a consequence, classical interpretations of econometrics may not fully apply. The construction of the CFSM-I was not the exception to this "apparent rule in econometric modeling". In building this model, it was ineludible to accept some estimated equations with poor statistical fit and/or with an important variable (according to theory) statistically insignificant or absent, because of its sign resulted inconsistent with what is expected in the theory. An outstanding example was the estimated equation for the supply of manufactured wood products of the wood industry (S^w), despite the multiple tries to obtain a better estimated equation with the data available.

There is not much to do about this fact, other than waiting for future data to get a better estimated equation. However, one characteristic of the all the CFSM-I equations, except for that of the consumption of unprocessed wood for firewood (C^{FWrw}), is that they track very well the historical data and behave relatively well, or at least acceptably so, in the context when all four out of the five markets modeled are connected (i.e., in the context of the CFSM-I simulated as a unit under the market clearing situation, excluding the FWrw market). The behavior of the equations in the cited context is what is expected to give enough confidence on the results of the policy experiments simulated by using the CFSM-I, and on the policy recommendations derived from them. The reader might have already recalled that all experiments simulated and the policy recommendations in this research exclude the FWrw market.

Data concessions

As some data gaps for estimating the behavioral equations of the CFSM-I were present, the path selected under this research was to exhaustively explore all the possible sources, and estimate the data gaps. An important part of the values estimated, especially of data related to the 1970-1993 Supply and Use tables (SUT) of the National Accounts, accounted mainly for simple calculations to separate data of the different markets that had never been done before, due, perhaps, to a lack of interest in the subject or because the information already in the SUTs that allow the separation of the data has been overlooked (e.g. data related to the MWrw and FWrw markets). In general, all data estimated under this research are considered robust, and any attempts to improve those estimates would be marginal, as most of the sources and methodological steps for estimating them may have been exhausted in this research. A perfect example would be the sources and methodology for obtaining the time series on forest plantation evolution between 1954 to 2021. Although robust, there will be inevitable imprecisions in the body of information consolidated for the CFSM-I, because data is simply inexistent.

Additional supplementary research

Limitations on the quality of available data for the Colombian firewood market (which is mostly informal) and a structural change in this market in 1990 could be the culprits behind the results of a C^{FWrw} estimated equation, which does not perform well in either isolation or when the market of FWrw is connected to the other four markets modeled under the CFSM-I. Further research is needed for the market of unprocessed wood for firewood to improve its understanding as an isolate market and its behavior when performing as part of the CFSM-I.

A third phase of the CFSM (CFSM-III), not included in the conceptual map presented in this thesis document, but that could be part of future research, corresponds to: a) develop the CFSM spatialization (using the Colombian geographical regions and the National Accounts by Colombia's Departamentos frameworks); b) incorporate a CFSM graphical interface for using (and producing) graphical inputs (outputs) of, or integrate the CFSM to, both Colombia's forest and climate change monitoring system – SMBYC (IDEAM) and information system for agricultural and rural Planning, SIPRA (UPRA) and c) link the CFSM to the software tool developed by the author of this research in 2007 for measuring the Colombian forest sector products competitiveness and profitability. The theoretical, conceptual, and methodological approach used in this research for building the CFSM will easily progress with a), b) and c).

Finally, it would be interesting to investigate in detail two additional topics. How the efficiency of the forest markets is affected by the fact that, to some extent, part of the Colombian forests are public goods, and some of the Colombian forest products (goods and services) exhibit nonexcludable and/or non rivalrous characteristics. Second, if illegal logging and other illegal activities happening in Colombia (e.g. gold illegal mining) may be other causes of market failures in this country, particularly in its market of MWrw.

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Digital Appendices

Appendix 3-1 Factors of conversion for wood forest products used in the CFSM

Appendix 4-1 Database for the Forest Sector in Colombia (CFS-DB)

Appendix 4-2 Statistical Indicators of the Colombian Forest Sector and Estimation of CFSM-I policy variables related to volumes of wood (VAS, VH, and VAST)

Appendix 4-3 Analysis of the Forest Markets Modelled under the CFSM-I

Appendix 5-1 Documentation of Estimation process for Behavioral Equations of CFSM Phase I

Appendix 5-2 Validation process of the CFSM-Phase I – Graphs and Tables and Others

Appendix 5-3 CFSM Phase I Software Application and User's Manual

Appendix 6-1 Colombian Forest Plantation Growth and Yield Simulator (SCRPFC)

Appendix 6-2 Growth and yield tables for commercial forest plantations in Colombia

Appendix 6-3 Simulated expansion of areas of commercial forest plantations in Colombia by year

Appendix 6-4 Simulated expansion of areas of commercial forest plantations in Colombia by species

Appendix 6-5 Simulated expansion of areas of commercial forest plantations in Colombia by geographical location

Appendix 6-6 Data on stands for scenarios simulated and the management regime applied

Appendix 7-1 Data on exogenous variables of the CFSM-I for period 2014-2047

Appendix 7-2 Results of the CFSM-I simulations for Category I and II

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