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Presentation and theorical foundations

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Décembre 2010

Document de travail
n° 2010-04

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The French Forest Sector Model: version 1.0.
Presentation and theorical foundations

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Décembre 2010

Document de travail du LEF n°**2010-04**

Résumé

Le modèle du secteur forestier français : présentation et fondations théoriques

Le Modèle de Secteur Forestier Français (MSFF) représente à la fois la dynamique économique du secteur forestier et la dynamique de la ressource forestière française. Pour cela il est construit sur la base de deux modules interconnectés. Tout d'abord, un module économique représente les comportements des consommateurs et des producteurs de produits bois dans un modèle en équilibre partiel. Ce module représente la demande de produits bruts *w*, leur transformation en produits transformés *p* et la demande pour ces produits transformés. Le module de dynamique de la ressource quant à lui représente le stock forestier en forêt et sa dynamique. Le module économique et le module de ressource sont doublement liés. Premièrement la dynamique biologique dépend des taux de récoltes donnés par le module économique. Deuxièmement, dans le module économique, les fonctions d'offre de bois brut dépendent de la quantité de bois disponible en forêt. Le MSFF est un outil de référence pour modéliser les implications des politiques climatiques sur le secteur forestier français. Jusqu'à présent il a été utilisé pour (1) modéliser les conséquences sur la filière de politiques stimulant la consommation de bois énergie dans un contexte d'incertitude sur la disponibilité de la ressource et (2) pour comparer les implications de deux politiques climatiques opposées : d'une part le paiement pour la séquestration du carbone en forêt et d'autre part la stimulation de la demande de bois énergie.

Mots clés : modélisation du secteur forestier, modèle bioéconomique.

Abstract

The French Forest Sector Model (FFSM) jointly models the economic dynamic of the French forest sector and the biological dynamic of the French forest resource. To do so, two modules are interconnected. First, an economic module represents producers and consumers behaviors as well as the evolution of wood products prices in a partial equilibrium framework. It represents supply of primary wood products *w*, their conversion in final wood products *p* and the demand for final products *p*. Second a forest resource dynamics module represents forest stock in standing forest and its dynamics. The forest resource dynamics and the economic modules are linked in two. First, wood stock dynamics depend on harvesting rates which derive from the economic module. Second, in the economic module, supply functions depend on available wood stock. The FFSM is likely to become a powerful tool to assess climate policies implications for the forest sector. So far, the FFSM has been used (1) to model the impacts of fuelwood stimulating policies on the sector under uncertainty over the availability of the resource and (2) to compare the implications of two opposite policies: the payment for forest carbon sequestration and the stimulation of fuelwood demand.

Key words : Forest sector modelling, bioeconomic model.

Classification JEL : C52, Q23, Q42, Q54.

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1 Introduction

Is the French metropolitan forest a strong, healthy and expanding forest? This is what data indicate: since the middle of XIXe century, the French forest area has been growing [Cinotti, 1996] and has increased by about 68000 ha/yr since 1980 to reach, in 2010, about 16 Mha, i.e., one third of the French metropolitan territory. Meanwhile, however, the French wood industries are suffering: the number of sawmills is decreasing and French trade balance for wood products is showing a large deficit - the second largest of trade French balance [Puech, 2009]. This paradox of a strong forest resources dynamics and weak forest sector industries is a major concern which the State tries to overcome by stimulating fuelwood and construction wood sub-sectors and by including the forest sector in national climate change mitigation strategy.

In this context, there is an increasing demand for expertise on the economics of the forest sector. Several assessments already published focus on technical or feasibility aspects such as biomass availability for an increasing consumption ([Colin et al., 2009], [Ginisty et al., 2009] and [IFN, 2005]), technologies development ([Puech, 2009]), potential of carbon sequestration in forest stands and in wood products ([Hofer et al., 2007] for the Swiss case). Yet these studies do not capture economic determinants of forest sector dynamics such as prices (*e.g.,* carbone price, wood price, wood substitutes prices) or costs (*e.g.,* sequestration costs, innovation costs, public policies costs). The French Forest Sector Model (hereafter the FFSM) aims at filling this gap by jointly modeling the economic dynamic of the French forest sector and the biological dynamic of the French forest resource. To do so, we develop two modules. First, an economic module represents producers and consumers behaviors as well as the evolution of wood products prices in a partial equilibrium framework. Second a forest resource dynamics module represents forest stock in standing forest and its dynamics. The FFSM is the first model to be specifically built for the French forest sector [1]. It relies on the same basic framework as existing global, continental or national models such as the GTM ([Kallio et al., 1987]) and CGTM ([Cardellichio et al., 1989]) — both developed at the *International Institute for Applied Systems Analysis*, the Global Forest Product Model (GFPM, [Buongiorno et al., 2003]), or the EFI-GTM ([Kallio et al., 2004]). Yet, it differs from these models on three aspects: (1) the very detailed French data used, (2) the way international trade is represented and (3) the way forest resource dynamics is represented. This paper aims at presenting the FFSM. It is organised as follows. In section 2 we draw a genealogy of forest sector models to understand the historical foundations of the French Forest Sector Model. In section 3 we present the FFSM equations and provide an analytical resolution. In section 4 we detail the calibration process. Finally in section 5 we define the domain of validy of the current version and the perspectives for future versions.

[1] A first attempt was carried out by Terreaux and Peyron for Burgundy in 1986 ([Terreaux, 1986] and [Peyron, 1986]).

2 A brief History of forest sector models

2.1 Early concerns

Concerns about the projection in the future of wood supply and wood products demand are not recent. In 1920, in the U.S., the Secretary William M. Meredith reported to the President Taylor that "[they were] using timber four times as fast as [they were] growing it" (in [Vaux and Zivnuska, 1952]). Nine years later, during a congress on deforestation in the United States of America, Gifford Pinchot was still worrying about the sustainability of forestry practices :

> "The fact is that our forests are disappearing at a rate that involves most serious danger to the future prosperity of our country and that little or nothing that counts is being done about that" ([Pinchot, 1929] in [Berck, 1979]).

Both Pinchot and Meredith did base their analysis on the comparison of future demand and supply, both projected with *gap analysis* models. These models did not include any economic behavior but used past trends to project future demand and projected limited increase in supply. Hence the growing gap and and the fall-off in standing wood stock in the long run.

2.2 From the 1930's to the 1970's: from *gap analysis* to the need of a price projection

Despite the debate surrounding the gap approach [2], *gap analysis* models were used for the three first Timber Resources for America's Future Outlook Studies (1958, 1965, 1973) in which demand projections were based on past trends and supply volumes were projected by extrapolating trends or trends coupled with adjustments for changes in growth ([Haynes and Adams, 2007]).

As stated by [Haynes and Adams, 2007], prior to mid 1970's, prices in the forest sector had been relatively stable over long periods so that price and its determinants were not really seen as a policy matter [3]. But the rapid inflation in the late 1970's and in the 1980's encouraged the development of models that used standard supply and demand balance in order to focus on price and rates of price changes.

[2] The lack of explicit links between supply and demand processes in the gap approach was already pointed out in the 1950's by [Vaux and Zivnuska, 1952] that supported the idea of a "moving equilibrium" over time ([Adams and Haynes, 2007]).

[3] Moreover, at that time, works on wood supply was led by a normative approach, in particular thanks to the paper by Samuelson *Economics of forestry in an evolving society* [Samuelson, 1976] that made Faustmann theory [Faustmann, 1849] famous.

2.3 The 1980's: the lauch of super-models

The 1980's were characterized by the developments of global models aimed both at capturing inter-regional trade complexity and at integrating demand, supply and price calculation for a large number of forest products and sub-sectors.
Three *modeling tribes* can be distinguished.

First recursive models solved the equilibriums one after another, taking into account changes in technological systems. These models were developed both in Europe, at the International Institute for Applied Systems Analysis (IIASA created in 1972) and in the U.S., at the US Forest Service's Resource Planning Act's (RPA) instigation.
The Timber Assessment Market Model (TAMM, [Adams and Haynes, 1980]) was the first supply-demand model used to carry out RPA Timber Assessments reports, replacing *gap analysis* Outlook Studies. Meanwhile, forest sector studies within IIASA started in 1980 and led to the development of two models: the Forest Sector Prototype Model (FSPM, [Lönnstedt, 1983a] and [Lönnstedt, 1983b]) and the Global Trade Model (GTM, [Kallio et al., 1987] and the the Cintrafor Global Trade Model CGTM [Cardellichio et al., 1989]).
In 1985, PELPS system (Price Endogenous Linear Programming System) was developed at the University of Wisconsin and within the support of the U.S. Forest Service ([Gilless and Buongiorno, 1985]). This computer programming system enabled the design of regional market models using Samuelson spatial price equilibrium theory [Samuelson, 1952]. PELPS was used, and is still used, to develop different models among which the North American pulp and paper industry PAPYRUS model ([Gilless and Buongiorno, 1987]). A few years later, the North American Pulp and Paper Model (NAPAP), the successor to PAPYRUS was designed to project pulp and paper industries in a greater detail and was linked to TAMM in order to reflect interrelationships between solid wood products industries and pulp and paper industries ([Ince and Buongiorno, 2007]).
What is interesting is that IIASA and U.S. Universities worked together, as an example the first operational version of the GTM used the PELPS software [Ince and Buongiorno, 2007].
All these models have the same theoretical structure as and share some modules with TAMM. They are all partial equilibrium models with a dynamic recursive structure. In particular as partial equilibrium models they do not attempt to predict the feedback of the rest of the economy on the forest sector: it is usually assumed that is most countries, the forest sector is too small to affect macrovariables such as GDP [Buongiorno et al., 2003].

In parallel, another group of models was developped based on Hotelling's theory of non renewable ressources ([Hotelling, 1931]) and on the work of Solow on natural ressources economics ([Solow, 1974]). Models of this second group project a path of optimal harvest decisions according to current and future expected prices and standing wood volumes for each age class. This intertemporal approach was justified by the use of "rational expectation" theory.[4] These models differ from those of the first category on two points: they are normative models which do not attempt to project actual behaviors and they are supply model that do not take into account demand side.
One of the first economists to introduce this modeling framework was Berck ([Berck, 1979]) with a study of douglas fir stands in the United-States. Lyon then introduced the intertemporal process within a global model: the Timber Supply Model ([Lyon, 1981], [Sedjo and Lyon, 1989] and [Sedjo and Lyon, 1996]). The relationship between supply dynamics and stand structure dynamics was new since recursive dynamic models such as TAMM did not consider stand structure as a control variable.

A third trend in forest sector modeling encompasses models aimed at addressing land use change issues by linking agriculture sector model to forestry issues. Probably most famous one is FASOM which fits in TAMM original structure, in particular by integrating Samuelson spatial equilibrium theory, but with an intertemporal frameworks [Adams et al., 1996]. Thus, from a resolution framework point of view these models can be linked to the second category. However the consideration of demand functions and the search for a spatial equilibrium and their links with other sectors such as agriculture sector make them more complex.

2.4 After 2000: two complementary trends

Recent insights in forest sector modeling result in two different but complementary trends:
First the need for global model, simple enough to capturate aggregate trends. It is the case of the Global Forest Products Model (GFPM) that was developed within an advanced version of PELPS sys-

[4] In fact these models lie on *perfect foresight* theory, that assumes all agents can trade at any time on present and future markets [Arrow, 1978]. A frequent and persistent confusion exists between perfect foresight framework and rational expectations theory [Kantor, 1979] and, as a consequence, the term *rational expectations* is often used in place of *perfect foresight*. Yet the two concepts are not identical. Rational expectation theory, as put in the original article by Muth in 1961 [Muth, 1961] assumes that agents work out their expectations from all the information they can collect. Their expectations are then updated as soon as new pieces of information appear. In this case, the role of time is obvious: agents improve their expectation as time goes by. In the perfect foresight framework, on the other hand, the role of time completely disappears: past, present and future are perfectly known, as if all agents were omniscient and perfectly aware of future economic conditions. In a way, defining these models as *dynamic* is a misuse since all equilibriums are solved all at once, without any temporal idea.

tem ([Buongiorno et al., 2003]) and the European Forest Institute — Global Trade Model (EFI-GTM, [Kallio et al., 2004]) based on GTM and CGTM.
Second the need for national or regional models able to cope with local specificities. This trend led to the consutruction of more detailed models that encompasse one specific economy such as the Norwegian Trade Model (NTM, [Bolkesjø, 2004]), the U.S. Forest Products Module (USFPM, [Kramp and Ince, 2010]), the European adaptation of FASOM resulting in the model EUFASOM [Schneider et al., 2008]. The French Forest Sector Model is being developed within this approach.

3 The French Forest Sector Model

3.1 Overview

3.1.1 A partial equilibrium model within a recursive and dynamic framework

The French Forest Sector Model (hereafter called the FFSM), is a recursive dynamics model with an annual time step. It thus belongs to the model family composed of CGTM, EFI-GTM, NTM or GFPM. Nevertheless it differs from these models on three points:

- First it focuses on France: the FFSM has 23 regions, 22 within metropolitan France (matching French administrative regions) and one aggregate "Rest of the World" region.
- Second the FFSM models international trade using Armington theory [Armington, 1969] which assumes imperfect substitution between domestic and foreign products.
- Third the FFSM stems from a specific module that captures French forest specificities, notably the inter- and intra-regional species and the sylvicultural diversity.

In short, the FFSM works as follows: At year t, the economic module solves the spatial equilibrium and calculates timber supply. Supply, translated in harvest levels, is then entered as input into the resource dynamics module which yields the new available wood stock for year t+1 (taking into account both harvest and natural increments). Then, at t+1, a new economic equilibrium is computed, given the available wood stock, and so on.

The forest resource dynamics and the economic modules are thus linked in two. First, wood stock dynamics depend on harvesting rates which derive from the economic module. Second, in the economic module, supply functions depend on available wood stock.
The FFSM economic module represents supply of primary wood products w, their conversion in final wood products p and the demand for final products p.

Four primary wood products w are distinguished: hardwood roundwood (hereafter HRW), softwood roundwood (hereafter SRW), fuelwood (hereafter FW) and pulpwood (hereafter PW). Six final products p are distinguished: hardwood sawnwood (hereafter hsw), softwood sawnwood (hereafter ssw), plywood, panels, pulp and fuelwood.

3.1.2 How to distinguish products p according to their origin and products w according to their destination: insights from Armington theory (1969)

Both final and primary products produced in French regions are assumed to be perfect substitutes one to each other, whatever the regions considered (*e.g.*, Lorraine fuelwood and Bretagne fuelwood are perfect subtitutes). However, at the international level, we do not observe a unique price for wood products, even by taking into account transport costs (except for pulp). This suggests that both primary and final wood products are not homogeneous worldwide. This can be due to different reasons *e.g.,* differences in consumption habits, differences in social norms, transaction costs or informational rents. To model this lack of homogeneity we use Armington theory ([Armington, 1969]) and assume that French products and foreign products are imperfect substitutes. Following Armington we distinguish products according to their place of production, either national or foreign. For example, fuelwood is a good, but there are two fuelwood products: French fuelwood and Rest of the World fuelwood.

Armington's theory characterizes demand functions by making four main assumptions. First consumers' preferences for a product related to one good are assumed independant from the consumption of products related to other goods (*e.g.,* consumption of French fuelwood is independant from consumption of French roundwood). Second, country's shares of the French market for each good are unaffected by changes in the size of the market as long as relative prices remain constant. In other words market shares only depend on relative prices. Third elasticities of substitution between any two products competing in the same market are assumed constant (independently of market shares). Finally these elasticities are equal for each pairs of products competing in the same market.

Under these four assumptions, the demand function for final product p in region i and at year t is a constant elasticity of substitution (CES) function:

$$D_{p,i,t} = \left[\left(1 - b_{D_{p,i}}\right) LD_{p,i,t}^{\frac{\varphi_{p,i}-1}{\varphi_{p,i}}} + b_{D_{p,i}} M_{p,i,t}^{\frac{\varphi_{p,i}-1}{\varphi_{p,i}}} \right]^{\frac{\varphi_{p,i}}{\varphi_{p,i}-1}} \tag{1}$$

Where:

- $D_{p,i,t}$ is the demand for what we will call *composite products* p, in region i at year t;
- $LD_{p,i,t}$ is the demand for products p *produced in France*, in region i at year t;

- $M_{p,i,t}$ is the demand for products p *produced abroad* or the demand for imports of p, in region i at year t;
- $\varphi_{p,i}$ is the elasticity of substitution between domestic products p and foreign products p;
- $b_{D_{p,i}}$ is a constant parameter such that $0 < b_{D_{p,i}} < 1$.

Given the assumption of independance, the demand for French and foreign products $LD_{p,i,t}$ and $M_{p,i,t}$ can be expressed as a function of $D_{p,i,t}$ and of relative product prices in the market of products p ([Armington, 1969], p 161, p 165, p 167, p 172). This results in the following specifications:

$$M_{p,i,t} = b_{D_{p,i}}^{\varphi_{p,i}} D_{p,i,t} \left(\frac{\tilde{P}_{p,i,t}}{P^*_{p,t}} \right)^{\varphi_{p,i}} \tag{2}$$

$$LD_{p,i,t} = (1 - b_{D_{p,i}})^{\varphi_{p,i}} D_{p,i,t} \left(\frac{\tilde{P}_{p,i,t}}{P_{i,p,t}} \right)^{\varphi_{p,i}} \tag{3}$$

From these specifications, one can derive the price of composite product p:

$$\tilde{P}_{p,i,t} = \left(P_{p,i,t}^{1-\varphi_{p,i}} \left(1 - b_{D_{p,i}}\right)^{\varphi_{p,i}} + P_{p,t}^{*1-\varphi_{p,i}} b_{D_{p,i}}^{\varphi_{p,i}} \right)^{\frac{1}{1-\varphi_{p,i}}} \tag{4}$$

Where:

- $\tilde{P}_{p,i,t}$ is the price of composite product p, in region i at year t;
- $P_{p,i,t}$ is the price of product p produced in region i in France, in region i at year t;
- $P^*_{p,t}$ is the price of product p produced abroad, at year t;

An important property of Armington specification is that money expenditure is balanced in each market p :

$$\tilde{P}_{p,i,t} D_{p,i,t} = P_{p,i,t} LD_{p,i,t} + P^*_{p,t} M_{p,i,t} \tag{5}$$

Armington theory is designed, in the original article, for the demand function. Following Geraci and Prewo [Geraci and Prewo, 1982] we transpose it to the supply function. We thus assume French primary

wood products are imperfect substitutes to foreign primary wood products and that producers differentiate the place of consumption of their products given relative prices and given a constant elasticity of transformation. We thus postulate that supply for composite products w can be written as:

$$S_{w,i,t} = \left[\left(1 - b_{S_{w,i}}\right) LS_{w,i,t}^{\frac{\varphi_{w,i}-1}{\varphi_{w,i}}} + b_{S_{w,i}} X_{w,i,t}^{\frac{\varphi_{w,i}-1}{\varphi_{w,i}}} \right]^{\frac{\varphi_{w,i}}{\varphi_{w,i}-1}} \tag{6}$$

Where:

- $S_{w,i,t}$ is the supply of composite products w, in region i at year t;
- $LS_{w,i,t}$ is the supply of products w to the French market, in region i at year t;
- $X_{w,i,t}$ is the supply of products w to foreign markets, *i.e.,* the amount of exports of w, from region i at year t;
- $\varphi_{w,i}$ is the elasticity of substitution between the products w sold abroad and the products w sold in France;
- $b_{S_{w,i}}$ is a constant parameter such that $0 < b_{S_{w,i}} < 1$.

As for demand specifications, we can express $LS_{w,i,t}$ and $X_{w,i,t}$ as a function of $S_{w,i,t}$ and of relative product prices in the market of products w:

$$X_{w,i,t} = b_{S_{w,i}}^{\varphi_{w,i}} S_{w,i,t} \left(\frac{\tilde{P}_{w,i,t}}{P^*_{w,t}} \right)^{\varphi_{w,i}} \tag{7}$$

$$LS_{w,i,t} = (1 - b_{S_{w,i}})^{\varphi_{w,i}} S_{w,i,t} \left(\frac{\tilde{P}_{w,i,t}}{P_{i,w,t}} \right)^{\varphi_{w,i}} \tag{8}$$

From these specifications, one can derive the price of composite product w:

$$\tilde{P}_{w,i,t} = \left(P_{w,i,t}^{1-\varphi_{w,i}} \left(1 - b_{S_{w,i}}\right)^{\varphi_{w,i}} + P_{w,t}^{*1-\varphi_{w,i}} b_{S_{w,i}}^{\varphi_{w,i}} \right)^{\frac{1}{1-\varphi_{w,i}}} \tag{9}$$

Where:

- $\tilde{P}_{w,i,t}$ is the price of composite product w, in region i at year t;
- $P_{w,i,t}$ is the price of product w in France, in region i at year t;

- $P^*_{w,t}$ is the price of product w abroad, at year t;

And where:

$$\tilde{P}_{w,i,t}S_{w,i,t} = P_{w,i,t}LS_{w,i,t} + P^*_{w,t}X_{w,i,t} \tag{10}$$

In this version 1.0 of the FFSM we assume France is trading with a single "region", the *rest of the world*. For future versions it will be useful to divide this block in several smaller and more homogeneous regions.

We choose represent only exports of primary products w and imports of products p. Imports of primary products w and exports of final products p are not modelled. This is consistent with past trends patterns. In addition, we assume that introducing imports and exports at both ends of the sector only is sufficient to capture the aggregate impacts on international trade of policies at both end of the sector.

3.1.3 Modeling supply of composite products w

In each region i, we assume that the amount of composite product w supplied to the market depends on the price of w *and* on the stock of wood in standing forest. Moreover we divide equation of supply at year t by equation at year $t-1$ in order to obtain the variation of supply between year $t-1$ and year t that depends on both the variation of price between $t-1$ and t and the variation of available stock in standing forest between $t-1$ and t. Thus, the supply function can be written:

$$S_{w,i,t} = S_{w,i,t-1}\left(\frac{\tilde{P}_{w,i,t}}{\tilde{P}_{w,i,t-1}}\right)^{\epsilon_w}\left(\frac{F_{w,i,t}}{F_{w,i,t-1}}\right)^{\beta_w} \tag{11}$$

Where:

- $S_{w,i,t}$ is the supply of composite products w in region i and at year t;
- $\tilde{P}_{w,i,t}$ is the price of composite product w in region i and at year t;
- $F_{w,i,t}$ is the stock of wood in standing forest in region i and at year t, that can be harvested and that can enter the industry of product w in region i and at year t;
- ϵ_w et β_w are positive and represent price elasticity of supply and stock elasticity of supply, respectively.

It is important to note here that one unit of w produced in region i may be sent to 3 different destinations: it may be transformed in region i, it may be sent to another French region and be transformed in that region or it may be sent abroad.

We thus assume that supply relies on wood stock dynamics in standing forest $F_{w,i,t}$. $F_{w,i,t}$ is the economically harvestable stock at year t, it implicitly contains a range of ages or diameters classes that can be harvested at year t.

A different way to assess the dynamics in forest owners decisions would be to make wood supply dependent on both present price and future expected price (for exemple using Faustmann specifications, [Faustmann, 1849]). In spite of a lack of theoretical and empirical knowledge regarding forest owners expectations, some existing material (*e.g.,* [Provencher, 1995] and [Kéré, 2009]) could be explored in the future.

3.1.4 Modeling demand for composite products p

In every region i, we assume that the demand for composite product p depends on the the current composite price. As for supply, we divide equation of demand at year t by equation at year $t-1$ in order to obtain the variation of demand between year $t-1$ and year t that depends on the variation of price between $t-1$ and t. Hence the following equation:

$$D_{p,i,t} = D_{p,i,t-1} \left(\frac{\tilde{P}_{p,i,t}}{\tilde{P}_{p,i,t-1}} \right)^{\sigma_p} \tag{12}$$

Where:

- $D_{p,i,t}$ is the demand for composite product p in region i at year t;
- $\tilde{P}_{p,i,t}$ is the price of composite product p in region i at year t;
- σ_w is the price elasticity of demand. Usually, it is a negative parameter.

This classical specification leaves out several economic factors, such as consumer income or the prices of non-wood substitutes [5] but also structural factors that affect demand on the medium and long term such as the penetration of new technologies into the market.

Finally, we can note that one unit of product p consumed in region i may come from three different places: it may have been transformed in region i, it may have been tranformed in another region and sent to region i or it may come from abroad.

3.1.5 Modeling transformation

We represent transformation of products w into products p through an input output matrix (Leontief matrix) that gives the volumes of products w required to produce one unit of product p. Thus total

[5] The price of some substitutes is taken into account in a new extension of the FFSM [Barthes, 2010].

demand of primary product w in region i at year t is a linear function of the quantity of the final products p produced (equation 13).

$$D_{w,i,t} = \sum_{p} a_{p,w} S_{p,i,t} \tag{13}$$

Where:

- $D_{w,i,t}$ is the total demand for primary product w in region i at year t;
- $a_{p,w}$ is the input-output coefficient, *i.e,* the volume of w required to produce one unit of p;
- $S_{p,i,t}$ is the production of final product p in region i at year t.

As noted above, in the current version of the model, transformation industries in region i can transform products w either originating from region i or from other French regions but not from abroad. In other words, transformation industries produce products p sold on the French market from products w produced on the French market.

Moreover, transformation industries support a production cost c_p for every unit of product p produced (we assume here that this cost is independent of the quantity produced). This production cost covers all external factors such as labor, energy, etc. Finally, a regional maximal production capacity $K_{p,i,t}$ is defined. We assume $\forall i, p, S_{p,i,t} < K_{p,i,t}$.

3.2 Finding the FFSM equilibrium conditions: an analytical approach

This section explains how FFSM computes market equilibriums for primary and final goods.

3.2.1 Application of Samuelson theory to the FFSM

Compared with Samuelson study case, the FFSM copes with two major structural differences. First supply functions and demand functions are not specified for the same products. Indeed the FFSM represents transformation of primary products w into final products p. In a sense the FFSM deals with another group of agents, the transformation industries, which does not exist in the Samuelson case study.

The other major difference is the distinction of products regarding their place of production or their place of consumption through Armington theory. Supply and demand functions are specified for composite - and thus heterogeneous - products whereas Samuelson spatial equilibrium method deals only with domestic homogenous products. Are Samuelson conditions respected when Armington theory is introduced? Since domestic variables (supply, demand and prices) are linked to foreign variables through Armington specifications, the answer is not intuitive and requires an analytical resolution of the model.

3.2.2 The Lagrangian

We assume $C_{p,i,j} > 0$ and $C_{w,i,j} > 0$. On a given year t, the sum of all agents surpluses equals:

$$
\begin{aligned}
&\sum_{p,i}\left[\int_0^{D_{p,i}} \tilde{P}_{p,i}(D)dD - \tilde{P}_{p,i} \times D_{p,i}\right] \\
&+\sum_{w,i}\left[\tilde{P}_{w,i} \times S_{w,i} - \int_0^{S_{w,i}} \tilde{P}_{w,i}(S)dS\right] \\
&+\sum_{p,i} S_{p,i,t}P_{p,i} - \sum_{p,i} c_p S_{p,i} - \sum_{w,i} D_{w,i}P_{w,i} \\
&+\sum_{p,i,j\neq i} \left(P_{p,i} - P_{p,j} - C_{p,i,j}\right) e_{p,i,j} \\
&+\sum_{w,i,j\neq i} \left(P_{w,i} - P_{w,j} - C_{w,i,j}\right) e_{w,i,j}
\end{aligned}
\tag{14}
$$

The first line is the surplus of composite products p consumers, the second line is the surplus of composite products w producers, the third line is the surplus of transformers of domestic products w into domestic products p. The fourth line is the surplus of trade agents who export products p (first term) or who import products p. Fifth line is the same for products w.
We call $H(\tilde{P}_{w,i}, P_{w,i}, S_{w,i}, \tilde{P}_{p,i}, P_{p,i}, S_{p,i}, D_{p,i}, e_{w,i,j}, e_{p,i,j})$ this objective function.
The maximisation problem can thus be written:

$$
\begin{aligned}
&Max_{\tilde{P}_{w,i},P_{w,i},S_{w,i},D_{w,i},LS_{w,i},X_{w,i},\tilde{P}_{p,i},P_{p,i},S_{p,i},D_{p,i},LD_{p,i},M_{p,i},e_{w,i,k},e_{w,b,i},e_{p,i,k},e_{p,b,i}} \\
&H(\tilde{P}_{w,i}, P_{w,i}, S_{w,i}, \tilde{P}_{p,i}, P_{p,i}, S_{p,i}, D_{p,i}, e_{w,i,j}, e_{p,i,j})
\end{aligned}
\tag{15}
$$

Subject to:

$$h_1 = LD_{p,i} + \sum_j e_{p,i,j} - S_{p,i} - \sum_k e_{p,k,i} = 0 \tag{16}$$

$$h_2 = \sum_p a_{p,w} S_{p,i} + \sum_j e_{w,i,j} - LS_{w,i} - \sum_k e_{w,k,i} = 0 \tag{17}$$

$$h_3 = D_{p,i} - \left[\left(1 - b_{D_{p,i}}\right) LD_{p,i}^{\frac{\varphi_{p,i}-1}{\varphi_{p,i}}} + b_{D_{p,i}} M_{p,i}^{\frac{\varphi_{p,i}-1}{\varphi_{p,i}}} \right]^{\frac{\varphi_{p,i}}{\varphi_{p,i}-1}} = 0 \tag{18}$$

$$h_4 = S_{w,i} - \left[\left(1 - b_{S_{w,i}}\right) LS_{w,i}^{\frac{\varphi_{w,i}-1}{\varphi_{w,i}}} + b_{S_{w,i}} X_{w,i}^{\frac{\varphi_{w,i}-1}{\varphi_{w,i}}} \right]^{\frac{\varphi_{w,i}}{\varphi_{w,i}-1}} = 0 \tag{19}$$

$$h_5 = D_{p,i} - \alpha \tilde{P}_{p,i}^{\sigma_p} = 0 \tag{20}$$

$$h_6 = S_{w,i} - \chi \tilde{P}_{w,i}^{\sigma_w} = 0 \tag{21}$$

$$h_7 = M_{p,i} - b_{D_{p,i}}^{\varphi_{p,i}} D_{p,i} \left(\frac{\tilde{P}_{p,i}}{P_p^*} \right)^{\varphi_{p,i}} = 0 \tag{22}$$

$$h_8 = X_{w,i} - b_{S_{w,i}}^{\varphi_{w,i}} S_{w,i} \left(\frac{\tilde{P}_{w,i}}{P_w^*} \right)^{\varphi_{w,i}} = 0 \tag{23}$$

$$h_9 = \tilde{P}_{p,i} D_{p,i} - P_{p,i} LD_{p,i} - P_p^* M_{p,i} = 0 \tag{24}$$

$$h_{10} = \tilde{P}_{w,i} S_{w,i} - P_{w,i} LS_{w,i} - P_w^* X_{p,i} = 0 \tag{25}$$

$$h_{11} = e_{p,i,j} \geq 0 \tag{26}$$

$$h_{12} = e_{w,i,j} \geq 0 \tag{27}$$

$$h_{13} = S_{p,i} \geq 0 \tag{28}$$

$$h_{14} = P_{p,i} \geq 0 \tag{29}$$

$$h_{15} = P_{w,i} \geq 0 \tag{30}$$

$$h_{16} = K_{p,i} - S_{p,i} \geq 0 \tag{31}$$

$$h_{17} = \sum_{u,i,g,e} V_{u,i,g,e,t-1} - \sum_{w,i} S_{w,i,t} \geq 0 \tag{32}$$

Constraints (16) and (17) are material balance equations, respectively for products p and w. In a region i, the quantity of products p or w produced plus the quantity of imports equals the quantity of products consumed plus the quantity exported.

Constraints (20) and (21) are the supply and demand function such as presented in section 3.1.4 and 3.1.3. For practical reasons we substituted the constant term of the demand equation by $\alpha = D_{p,i,t-1} \left(\frac{1}{\bar{P}_{p,i,t-1}} \right)^{\sigma_w}$. We did the same for supply function: $\chi = S_{w,i,t-1} \left(\frac{1}{\bar{P}_{w,i,t-1}} \right)^{\epsilon_w} \left(\frac{F_{w,i,t}}{F_{w,i,t-1}} \right)^{\beta_w}$.

Constraint (18) is the CES demand function for composite product p such as presented in equation (1). Constraint (22), also from Armington theory, links demand for domestic product p to demand for foreign product p. Symmetrically constraints (19) and (23) represent Armington specifications for products w. Constraints (24) and (25) correspond to the prices of the composite prices p and w. Inequality constraints (26) to (30) are constraints of non negativity. All the variables are assumed to be non negative, but thanks

to constraints (16) to (25), only these five remain necessary. Finally constraints (31) and (32) are capacity and stock constraints, respectively.

We do not present here the analytical maximization of the related Lagrangian and ask the lector to go to [**?**] for that.

3.2.3 Equilibrium conditions

The analytical resolution of the maximization problem results in an equilibrium matching two main conclusions :

- First, this equilibrium matches the Samuelson conditions. Indeed we found that if $e_{i,j} > 0$, then $e_{j,i} = 0$ and $\sum_{i,j}(P_i - P_j - C_{i,j}) = 0$. Thus, in any case, at equilibrium, $\forall i, j \in n, (P_i - P_j - C_{i,j})e_{i,j} = 0$. As a consequence, introducing Armington specification does not modify spatial equilibrium convergence.

- Second, if $S_{i,p} > 0$ then $P_{p,i,t} - \sum_p a_{p,w} P_{w,i,t} - c_p = 0$, which means that price of product p sold by the transformation industry exactly equals price of products w bought by transformers plus the cost of transformation. Thus the equilibrium found matches the non-profit condition for the transformation industries. Transformation industries are introduced as some kind of benevolent agents working as physical filters which do not attempt to maximize their own profits.

3.3 Forest resource dynamics module

3.3.1 A diameter class dynamics

The forest resource dynamics module represents the French forest stock and its dynamics over time. We choose a diameter-class approach instead of an age-class approach (such as EFISCEN does for example, [Schelhaas et al., 2007]) because the former approach is not appropriate to capture the dynamics of types of management such as uneven-aged stands for which there is no obvious link between age and diameter. Moreover diameter is problably a more pertinent criterion for forest management. The drawback of the method is that we must calculate, for each tree, the time necessary to grow from a diameter class to the next.

The forest resource dynamics module represents forest dynamics according to the following process (equation 33):

$$V_{u,t} = (1 - \frac{\Delta_t}{acc_u} - mort_u - h_{u,t})V_{u,t-1} + (\frac{\Delta_t}{acc_{u-1}} \frac{\nu_u}{\nu_{u-1}})V_{u-1,t-1} \tag{33}$$

Where:

- u is the diameter class index;
- Δ_t is the time step (one year);
- $V_{u,t}$ is the total volume of trees from diameter class u at the end of year t, that is after the harvest at year t;
- acc_u is the average rate of increment of trees in diameter class u. $\frac{\Delta_t}{acc_u}$ is thus the fraction of trees in diameter class u growing to the upper class at the end of the period, assuming equal distribution of trees within each diameter class;
- $mort_u$ is the average mortality rate in diameter class u;
- $h_{u,t}$ is the harvest rate at year t;
- ν_u is the average unit volume of trees in diameter class u; and
- $\frac{\nu_u}{\nu_{u-1}}$ is the coefficient rate of increment of unit volume when trees pass from diameter class $u-1$ to diameter class u.

Equation (33) means that, at the end of year t, diameter class u contains all the trees that were in class u at the end of year $t-1$, minus those that grew to the upper diameter class $u+1$ ($\frac{\Delta_t}{acc_u}$), minus those that naturally died ($mort_u$), minus those that were harvested ($h_{u,t}$), plus those "graduating" from lower class $u-1$ (last term in equation 33).
The main advantage of model (33) is that it represents stand dynamics with only three parameters (time of passage, rate of mortality and rate of increment). Moreover this equation can be calibrated thanks to the very detailed data obtained from the French Forest Inventory. The drawback is that this model is quite simple. In particular it does not represent the effect of density on the rates of increment. In other words we assume here that harvest intensity has no impact on forest dynamics. This is obviously a simplification, in fact thinning usually results in a growth bounce.

We use 13 diameter classes of 10 cm width each. The first diameter class is the 7,5 cm - 17,5 cm class, since trees under 7,5 cm are not listed in inventories. The last diameter class encompasses all trees above 137,5 cm. Diameter classes are indexed with their median diameter (for example 12,5 cm for the 7,5 cm - 17,5 cm diameter class).
The French forest is then divided into independent groups that we call *domains*. The disagregation of French forest inventory into domains is made according to three modalities:

- Region (i): we use administrative regions as a first level of disagregation, *i.e.,* 22 regions for metropolitan France.

- Species (e): within each region, we divide forests into three species classes: evergreen (land covered with more than 75 % of conifers), broadleaved (land covered with more than 75 % of broadleaved) and mixed forests (land covered with more than 15 % of broadleaved and more than 15 % of conifers);

- Type of management (g) : within each region and each species, three types of management are distinguished: high forest (even-aged and uneven-aged), coppices, and mixed stands (combination of coppices and high forests).

  We thus obtain $22 \times 3 \times 3 = 198$ domains.

  For each domain and for each diameter class, time of passage, rate of mortality and rate of increment are calibrated using the French Forest Inventory data. The forest dynamics for each domain and for each diameter class is thus given by equation (34), which is equation (33) with parameters specific to the domains and diameter classes considered.

$$V_{u,i,g,e,t} = (1 - \frac{\Delta_t}{acc_{u,i,g,e}} - mort_{u,i,g,e} - h_{u,i,g,e,t})V_{u,i,g,e,t-1} + (\frac{\Delta_t}{acc_{u-1,i,g,e}} \frac{\nu_{u,i,g,e}}{\nu_{u-1,i,g,e}})V_{u-1,i,g,e,t-1} \quad (34)$$

For each domain, the first diameter class volume $V_{1,i,g,e,t}$ is given exogenously. Thus planting, reforestation and regeneration are not considered as endogeneous variables in the model.

3.3.2 Harvest distribution

In FFSM, supply volume of products w are calculated taking into account global ressource availability (through the $F_{w,i,t}$ term in equation (11)) but without explicitely taking into account optimal distribution of harvest among diameter classes (as would be done in a perfect foresight model). The distribution is done *ex post*, based on *ad hoc* assumptions.

The key issue in this distribution is that the FFSM resource dynamics module has a higher resolution than the economic module. Precisely, the resource dynamics module divides stock in diameter classes (u) and domains resulting in $13 \times 198 = 2574$ groups. Th economic module, on the other hand, only distinguishes available stock $F_{w,i,t}$ by region i and by product w, *i.e.* in 22 regions $\times$ 4 primary products $w = 88$ groups.

This difference stems from the fact that we have more detailed data on the French forest dynamics than on french forest owners behaviors.

Stock $F_{w,i,t}$ in equation (21) is calculated as the sum of available volumes in a range of diameter classes u, types of management g and species e that may enter the product w industry at the end of year $t-1$. We call $G(w)$ the set of triplets (u, g, e) allocated to w industry.

$$F_{w,i,t} = \sum_{(u,g,e)\in G(w)} V_{u,i,g,e,t-1} \tag{35}$$

The distribution key that allocates triplets (u, g, e) to w industry is given in Table (1).

Table 1: **Allocation of wood from standing trees in industries** w

Domains			Primary products w		
Diameter class (u)	Type of management (g)	species (e)	FW/PW	HRW	SRW
12,5	Mixtures	All	×		
22,5 and 32,5	High forests and mixtures	Broadleaves	×	×	
22,5 and 32,5	High forests and mixtures	Evergreen	×		×
42,5 and more	High forests and mixtures	Broadleaves		×	
42,5 and more	High forests and mixtures	Evergreen			×
62,5 and less	Coppices	All	×		

Four comments can be made on Table 1:

1. First, we can observe that trees from diameter classes 22,5 cm and 32,5 cm from high forests and mixtures may enter any industry. Thus industries are possibly competing for the same standing trees. In particular, this means that $\sum_{w,i,t} F_{w,i,t} > \sum_w \sum_{(u,g,e)\in G(w)} V_{u,i,g,e,t-1}$. Thus, in order to be sure supply levels do not exceed maximum available stock, we add the following constraint to the maximisation problem: $\sum_{w,i,t} S_{w,i,t} < \sum_w \sum_{(u,g,e)\in G(w)} V_{u,i,g,e,t-1}$;

2. Fuelwood and pulpwood industries do not distinguish wood according to species. On the contrary, both hardwood roundwood and softwood roundwood distinguish species;

3. Fuelwood and pulpwood industries are competing for the same standing wood;

4. We consider trees from coppices bigger than 62,5 cm are kept only for their ecological value. This is why only trees from coppices smaller than or equal to 62,5 cm appear in the table;

5. Finally we exogenously choose the edge diameter between fuelwood/pulpwood and roundwood industries (here 37,5 cm). In the future this edge diameter could become an endogenous variable that could depend on product prices for example;

4 Calibration

Because of the recursive structure of equations (21), (20), (34) and (35), the resolution of the first equilibrium requires values for several economic variables at year $t-1$ and data on resource stock at $t-1$ and $t-2$ in order to calculate $F_{w,i,t}$ et $F_{w,i,t-1}$. Since 2006 is the last year for which all required data are available, we choose this year as the base year of the model. Thus 2007 is the first year for which equilibrium is calculated.
Calibration is as follows:

1. First, we measure the resource stock at the end of 2005, $V_{u,i,g,e,2005}$, for each domain. Then we calibrate all dynamics parameters (*i.e.,* $acc_{u,i,g,e}$, $mort_{u,i,g,e}$ and $\nu_{u,i,g,e}$).

2. Second, we calibrate economic data required to calculate economic equilibrium in 2007: domestic supply of w, exports of w and domestic prices of w ($LS_{w,i,2006}$, $X_{w,i,2006}$ and $P_{w,i,t}$) and also domestic demand for p, imports of p and domestic prices of p ($LD_{p,i,2006}$, $M_{p,i,2006}$ and $P_{p,i,t}$).

3. Third, we deduce from step 2 the harvest rate at year 2006 and we compute the resource stock at the end of 2006 $V_{g,u,i,e,2006}$ thanks to equations (34).

4. We then calibrate other economic parameters.

The first step of the process is detailed in the following section and the second and the last steps are explained in section 4.2. Step 3 is self-explanatory.

4.1 Resource dynamics module calibration

The calibration of the forest resource dynamics was carried out by the French Forest Inventory (IFN) in 3 steps:
(i) determination of forest stock at the end of year 2005 ($V_{u,i,g,e,2005}$) for each domain, (ii) calibration of all dynamics parameters and, (iii) determination of carbon quantities for each domain.
Basic information is provided here on each step. For more information, see [Colin and Chevalier, 2009].

- Step (i): end-of-year stock in 2005 is based on IFN inventory data.

- Step (ii): radial increment is measured on the five last annual rings before inventory took place. Thus radial increments consist in the 5 years increment (called $IR5$) and bark layer is added to obtain $IR5_{EC}$. We then calculate annual diameter increment by multiplying $IR5_{EC}$ by 2 and dividing it by 5, in mm/year. This average diameter increment is used to calculate the time of passage $\frac{\Delta_t}{acc_u}$.

The rate of natural mortality ($mort_{u,i,g,e}$) only takes into account usual natural mortality. In particular windfalls and unpredictable events which are difficult to model are not included. The French Forest Inventory only gives the number of trees that died 5 or less years ago. We divide it by 5 and then by the number of living trees in a specific domain to obtain the annual mortality rate for each domain (in unit/year).

- Step (iii): the carbon stock is estimated with the Carbofor project (2004) method and coefficient [Pignard, 2004]. From the total above-ground biomass volume, 2 coefficients are successively applied: first an infradensity coefficient depending on species (in order to convert m^3 into tons of dry material) and, second, an average rate of carbon in biomass (in order to convert tons of dry material into tons of carbon).

4.2 Economic module calibration

The following parameters are required to compute equilibrium in 2007: supply volumes of w ($LS_{w,i,2006}$ and $X_{w,i,2006}$), domestic prices of w ($P_{w,i,2006}$), foreign prices of w ($P^*_{w,i,2006}$), demand volumes of p ($LD_{p,i,2006}$ and $M_{p,i,2006}$), domestic prices of p ($P_{p,i,2006}$) and foreign prices of p ($P^*_{w,i,2006}$).

4.2.1 Primary products production (except fuelwood)

All quantities are expressed in cubic meters.
The annual sector survey (E.A.B) from the *Prospective and Statistic Service (SSP)* of the *French Ministry of Agriculture* provides regional productions for products w ($LS_{w,i,2006}$+ $X_{w,i,2006}$), given in Table 2 below. Regional exports $X_{w,i,2006}$ are estimated as the proportion of the regional production in national production. $LS_{w,i,2006}$ is then defined as the difference between regional production and regional export.

4.2.2 Final products demands (except fuelwood)

Demand for composite product p in 2006 is calculated through the following indirect process:

1. The annual sector survey (E.A.B) provides regional productions of hardwood sawnwood and softwood sawnwood ($S_{p,i,2006}$) (Table 2). Regarding other products p:

    - Pulp : National data from the *Confédération Française de l'Industrie des Papiers, Cartons et Cellulose* is allocated by region in proportion of region's share of pulp sector employment (source: *Industrial Statistics and Studies Service (SESSI)* of the *French Ministry of Economy, Industry and Employment*).
    - Panels : national production data (source *SESSI*) is allocated by region using confidential ratios provided by a producers union.

- Plywood: National production data (source *SESSI*) is allocated by region in proportion of regional's share of national sawnwood production.
- Other wood products (telegraph poles, posts, mine timber, sleepers, etc.) are excluded from the model since they represent very small volumes relative to other products.

2. Imports of p and exports of w for 2006 are provided by French customs service. Regional imports are estimated in proportion of region's GDP in 2006 (source : *National Institute for Statistics and Economic Studies (INSEE)*). Regional exports are estimated as the proportion of the 2002 regional exports (source: *French Custom Services*).

3. Given 1) and 2), we can calculate the 2006 apparent national consumption of each product as the sum of national production and imports minus exports ($CA_{p,2006}$ = $S_{p,2006}$ - $X_{p,2006}$ + $M_{p,2006}$). Regional apparent consumption is then computed in proportion of regional GDP.

4. We estimate 2006 regional consumption of domestic product p ($LD_{p,i,2006}$) as the difference between apparent cunsumption of p and imports of p calculated at 2) ($LD_{p,i,2006} = CA_{p,i,2006} - M_{p,i,2006}$).

5. Finally, we calculate demand for composite product p, $D_{p,i,2006}$ with equation (1). (Calibration of substitution elasticities $\varphi_{p,i}$ is detailed below).

4.2.3 Domestic prices

All prices in the model are in 2006 euros. To calculate primary and final products regional prices, we divide the total value of production given by *SSP* by the quantity produced. In the absence of regional production data, we assume that regional domestic prices are all identical. Prices are given in Table 3.

4.2.4 The case of fuelwood

Fuelwood is a specific case since some final products (such as pellets) are produced at the very same time trees are harvested. We do not have data detailed enough to distinguish between primary products and final products in this case. Given this context, we assume the total amount and the total value of fuelwood produced are also the total amount and the total value of fuelwood consumed. Moreover we must be careful as these data do only take into account comercialized fuelwood. Thus, the FFSM does take into account neither fuelwood home-consumed, nor fuelwood comercialized outside formal channels.

4.2.5 Input Output coefficients($a_{p,w}$)

Transformation coefficients are given in Table 4. The unit is roundwood equivalent m^3 per m^3 of final product.

Table 2: **Regional productions of primary products w and final products p (Mm^3)**

Regions	**HRW**	**SRW**	**FW**	**PW**	**fuelwood**	**hsw**	**ssw**	**plywood**	**panels**	**pulp**
AL	0,37	0,85	0,31	0,15	0,31	0,07	0,88	0	0	0
AQ	0,31	4,65	0,2	3,19	0,2	0,08	1,43	0,1	1,22	0,96
AU	0,14	1,35	0,17	0,27	0,17	0,07	0,69	0,01	0,18	0
BN	0,13	0,16	0,09	0,19	0,09	0,05	0,13	0,02	0,28	0
BO	0,51	0,67	0,29	0,67	0,29	0,16	0,34	0,04	0,48	0
BR	0,08	0,34	0,07	0,08	0,07	0,08	0,13	0,01	0,12	0
CE	0,41	0,27	0,19	0,59	0,19	0,09	0,14	0,08	0,92	0
CA	0,45	0,23	0,11	0,95	0,11	0,16	0,06	0,05	0,55	0
CO	0,01	0,03	0,01	0,05	0	0	0,02	0	0	0
FC	0,61	1,4	0,12	0,59	0,12	0,17	0,81	0,13	1,56	0
HN	0,17	0,12	0,06	0,27	0,06	0,06	0,13	0,02	0,28	1,8
IF	0,14	0,02	0,07	0,1	0,07	0	0,01	0	0	0
LR	0,02	0,54	0,07	0,3	0,07	0,01	0,19	0	0	0
LI	0,19	1,02	0,09	0,76	0,09	0,07	0,38	0	0	0,63
LO	0,66	1,1	0,27	1,21	0,27	0,25	0,68	0,01	0,18	0
MP	0,21	0,57	0,23	0,56	0,23	0,06	0,29	0,01	0,06	0,86
NP	0,17	0,03	0,12	0,08	0,12	0,07	0,01	0	0	0
PL	0,29	0,2	0,05	0,17	0,05	0,09	0,12	0,03	0,3	0
PI	0,54	0,06	0,14	0,51	0,14	0,1	0	0	0	0,26
PC	0,23	0,1	0,09	0,27	0,09	0,09	0,33	0	0	0
PA	0,01	0,16	0,15	0,36	0,15	0	0,06	0	0	0,91
RA	0,18	1,76	0,17	0,21	0,17	0,09	1,15	0	0	0

Table 3: **Domestic primary products and tranformed products prices in 2006 €**

HRW	**SRW**	**FW**	**PW**	**fuelwood**	**hsw**	**ssw**	**plywood**	**pulp**	**panels**
91	47	27	25	37	450	134	700	150	257

	fuelwood	hsw	ssw	plywood	panels	pulp
HRW		2		1,2		
SRW			1,83	1,2		
FW	1					
PW					1,43	1,53

Table 4: **Coefficients input / output (m^3 per m^3).*Sources: ([Peyron and Guo, 1995] for hardwood sawnwood and softwood sawnwood, [Peyron et al., 2005] and [Montagné and Niedzwiedz, 2009] for plywood and panels .***

Sawmills waste is taken into account in the FFSM since more than one m^3 of primary product is necessary to create one m^3 of final product. However this version of FFSM does not represent the use of these by-products to commercialy supply pulp and fuel sectors (we implicitely assume that they are home-consumed).

For fuelwood choose a transformation coefficient equals to 1, which means that to create 1 unit of final fuelwood the transformation industry uses 1 m^3 of primary fuelwood. Finally we assume average transformation cost equals 10 €/m^3.

4.2.6 Costs of production (c_p)

Except for fuelwood, unit costs of production in the FFSM come from [Buongiorno et al., 2003]. They are estimated for the United-States and for Italia in 1997. Empirical studies are necessary to improve these estimates in the future. For fuelwood we consider that the cost of production for pellets is 10 €/m^3.

Table 5: **Unit costs of transformation (€/m^3)**

Final product p	Transformation costs (€/m^3)
Fuelwood	10
Hardwood Sawnwood	70
Softwood Sawnwood	70
Plywood	225
Panels	90
Pulp	110

4.2.7 Transformation industries capacity and growth of capacity

We assume that regional transformation industry capacity in 2006 ($K_{p,i,2006}$) equals 1,5 times the level of production of 2006. Then we consider that transformation capacity grows by an annual 1%.

4.2.8 Unit transport costs for primary products($C_{w,i,j}$)

[Bourcet et al., 2007] assume that cost of transport in € per ton of transported primary product depends on average distance following the equation[6] :

$$C_{i,j,w} = \times(56 + 0,055M_{i,j}) \tag{36}$$

Where $M_{i,j}$ is the average distance between region i and region j.
Since FFSM unit is m^3, we introduce a supplementary transformation coefficient:

$$C_{i,j,w} = coef_w \times (56 + 0,055M_{i,j}) \tag{37}$$

Where $coef_w$ is the conversion coefficient from m^3 to tons of products. The distances between regions are the distances between the centers of gravity of each region. Conversion coefficient are given by [Peyron et al., 2005] and [Montagné and Niedzwiedz, 2009]:

- Hardwood roundwood: 0,892 ton/m^3
- Softwood roundwood : 0,716 ton/m^3
- Pulpwood : 0,571 ton/m^3
- Fuelwood : 0,690 ton/m^3

4.2.9 Final products transport costs ($C_{p,i,j}$)

The *Comité National Routier* survey [CNR, 2008] assesses the average transport costs for all products. This survey estimates the transport cost as the sum of three terms: a distance dependant term (input cost except labor), a distance dependant term (labor cost) and a number of days of transport dependant cost (capital depreciation).

[6]This formula is calibrated for distances smaller than 300 km. As a first approximation, we use it even for higher distances and as a mean for all primary products, independently, for example, of products shape.

We calibrated this formula for a 20 tons load. The survey assumes that, on average, in 2006, 13 % of the distance was covered empty, speed was 68,6 km/h and loading/unloading time took 3,26 hours. According to these figures, equipment was used during $0,16877 + 0,0017544 \times M_{i,j}$ days [7] .

$$C_{i,j,p} = coef_p \times 0,05 \times \left[1,13 \times TK \times M_{i,j} + (3,26 + \frac{M_{i,j}}{68,6} \times TH + (0,16877 + 0,0017544 \times M_{i,j}) \times TJ\right] \tag{38}$$

For 2006, the *Comité National Routier* survey gives these three cost components:

- lentght term TK = 0,428 €/km
- time term TH= 19,66 €/hour
- number of days term TJ = 151,01 €/day

Conversion coefficients ($coef_p$) are:

- Sawnwood (both hardwood and softwood) : 0,556 ton/m^3
- Plywood : 0,662 ton/m^3
- Panels : 0,644 ton/m^3
- Pulp: 0,442 ton/m^3
- Fuelwood : 0,690 ton/m^3

4.2.10 Elasticities

Price elasticities (ϵ_w for supply and σ_p for demand) and stock elasticities (β_w) come from [Buongiorno et al., 2003].
Substitution and transformation elasticities ($\varphi_{p,i}$ et $\varphi_{w,i}$) were estimated on the basis of Sauquet ([Sauquet et al., 2010]), Gallaway and al. ([Gallaway et al., 2003]) and Shiells and Reinert ([Shiells and Reinert, 1993]). Sauquet calculates roundwood transformation and substitution elasticities for France. Regarding the others elasticities, [Gallaway et al., 2003] and [Shiells and Reinert, 1993] indicate that, for the United States and before 1995, substitution elasticities range between 0,6 and 1,4 for the forest sector. Even if products considered in these studies are not exactly the same as those in FFSM, this interval provides a useful benchmark for the calibration. Selected figures are listed in Table 6.

[7] This equation is calibrated from the four examples given in Comité National Routier [CNR, 2008] and the total cost of transport is given by equation (38).

Table 6: **Price elasticities, substitution elasticities and transformation elasticities**

Products	**Price elasticities**	**Stock elasticities**	**Substitution and transformation elasticities**
	$(\epsilon_w\ ,\ \sigma_p)$	(β_w)	$(\phi_{w,i}\ ,\ \phi_{p,i})$
HWR	0,4	0,1	-0,75
SRW	0,4	0,1	-0,3
FW	1	0,1	-1,1
PW	1	0,1	-0,8
fuelwood	-0,3		0,9
hsw	-0,5		0,5
ssw	-0,4		0,8
plywood	-0,3		0,9
pulp	-0,5		1,3
pannels	-0,5		0,7

4.2.11 International prices, export costs and dynamics

To estimate international price for roundwood and fuelwood we use [FAO, 2006] data by dividing total exports value by the total exports amounts [8]. For pulpwood we retain a 30 \$ $/m^3$ value (*i.e.,* $\approx 24 euros/\mathrm{m}^3$) as put in the Pacific Rim Softwood Log Market ([(RISI), 2007]) report.

We then use GFPM to simulate international prices dynamics . For that we run GFPM for a reference scenario and we draw an average dynamics index for roundwood and fuelwood. We then use initial prices and this index to simulate dynamics of international price in the FFSM.

Price of imported transformed products are given in section 4.2.3. We assume this price is constant over the 2006-2020 period.

Table 7: **International prices for primary products and French prices for imported transformed products in 2006 (€/m^3)**

HRW	**SRW**	**FW**	**PW**	**fuelwood**	**hsw**	**ssw**	**plywood**	**pulp**	**panels**
80	72	29	24	64	502	218	625	192	322

[8] Correspondance between our products and FAO categories is as follows: for hardwood roundwood: Ind Rwd Wir (NC) Other (World +) ; for hardwood roundwood: Ind Rwd Wir (C) Other (World +) ; and for fuelwood: Wood Fuel + (World +).

4.2.12 $b_{w,i}$ et $b_{p,i}$ calibration

Parameters $b_{w,i}$ and $b_{p,i}$ used in Armington specification are calculated through equations (6) and (1) for the base year. Then, given domestic and international prices, price of composite products are calculated with equations (4) and (9).

4.2.13 Implementation

FFSM is encoded within G.A.M.S (General Algebraic Modeling System) software, linked to EXCEL ™ files for exogenous input parameters and output files.
After initialisation of parameters for 2006, G.A.M.S solves the maximisation program for 2007 and finds an equilibrium. Variables values associated to this equilibrium are used to calculate rate of harvest and forest stock at the end of 2007. This process is then repeated automatically every year over the selected period.

5 The domain of validity of FFSM : current state and perspectives

The actual FFSM version is valid only for short-term projections (10-15 years). Indeed we do not, for the moment, take precisely into account agent expectations and technical systems dynamics. More precisely we do not assume consumers and producers are expecting future conditions. We can reasonably tolerate this assumption for short-term horizons since a forest felling cycle lasts about one century and since adoption of new technologies by consumers, even if faster, is probably limited for such horizons. On the contrary, for longer-terms, the way we represent new markets penetration by consumers or the choice of felling cycle lenght would probably have significant impacts in the sector.
Moreover technical systems are highly dependant on time:

- The technologies inside the forest sector are evolving. Thus consumed products and transformation costs change.
- Long term forest stands dynamics is very complex. It includes on the one hand agents expectations and preferences (such as the choice of new species, new types of management) and, on the other hand, biophysical factors linked to climate change (change in forest productivity, new pathogens). Moreover, if we choose an even more integrated approach, forest area change also depends on other sectors such as agriculture or urbanization. This approach requires to study opportunity costs linked to land use change.

6 Conclusion

What makes the French forest sector specific is probably its rich and early forest history. The Royal Forestry School of Nancy was created in Nancy in 1824 and the first forestry code was born in 1346 with the support of Philippe de Valois. Different streams of forest managers and the plurality of climates on the French territory generated a unique diversity of species and types of management.

The aim of the FFSM is precisely to capture this diversity in order to propose accurate projections of the future conditions of the French forest sector. Today, the FFSM is the only model to project French forest sector conditions on a 15-20 years horizon. Both the economic module and the forest resource dynamics module are taking into account French specificities such as the diversity of types of management, the variety of species or the agents behaviors and preferences.

The current version of the FFSM has already been used to carry out two studies. The first paper assesses the impacts of an increase in fuelwood consumption over the competition with others sectors such as pulp industry [Caurla et al., 2009]. The second paper compares the potentially opposite impacts of a policy to retribute carbon in standing forest and a policy to stimulate fuelwood consumption [Lecocq et al., 2010]. Moreover Armington elasticities in the FFSM were specifically estimated by Sauquet [Sauquet et al., 2010] and a new version that includes the competition between wood products and substitutes has recently been the subject of a master thesis [Barthes, 2010].

Our future efforts will focus on modeling agents expectations and resource dynamics reaction to climate change in order to better assess dynamic in the model and, thus, to be able to make projection on a longer term horizon.

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7 Appendix

7.1 Model notations

7.1.1 Acronyms

Notation	Definition
FFSM	French Forest Sector Model
GFPM	Global Forest Product Model
EFI-GTM	European Forest Institute Global Trade Model
CGTM	Cintrafor Global Trade Model
TAMM	Timber Assessment Market Model
FASOM	Forest and Agriculture Sectors Optimization Model
EFISCEN	European Forest Information Scenario Model
IFN	Inventaire Forestier National (French Forest Inventory)
EAB	Enquête annuelle de Branche (Annual Sector Survey)
SSP	Service Statistique et Prospective (Prospective and Statistics Service)
SESSI	Service des Etudes et des Statistiques Industrielles (Industrial Statistics and Studies Service)
INSEE	Institut National de la Statistique et des Etudes Economiques (National Institute for Statistics and Economic Studies)
SRW	Softwood Roundwood
HRW	Hardwood Roundwood
FW	Fuelwood (as a primary product)
PW	Pulpwood
hsw	hardwood sawnwood
ssw	softwood sawnwood

7.1.2 French Regions

Symbol	Region
AL	Alsace
AQ	Aquitaine
AU	Auvergne
BN	Basse-Normandie
BO	Bourgogne
BR	Bretagne
CE	Centre
CA	Champagne-Ardennes
CO	Corse
FC	Franche-Comté
HN	Haute-Normandie
IF	Ile-de-France
LR	Languedoc-Roussillon
LI	Limousin
LO	Lorraine
MP	Midi-Pyrénées
NP	Nord-Pas-de-Calais
PL	Pays de la Loire
PI	Picardie
PC	Poitou-Charentes
PA	Provence-Alpes-Côte-d'Azur
RA	Rhône-Alpes

7.1.3 Indexes

Notation	Definition	Values
t	time	2006, 2007, 2008, ... , 2020
i,j	French regions	22 administrative regions
w	primary products	{hardwood roundwood, softwood roundwood, pulpwood, fuelwood}
p	final products	{hardwood sawnwood, softwood sawnwood, plywood, pannels, pulp, fuelwood}
g	type of management	{high forests, mixture of coppices and high forests, coppices}
e	species	{evergreen, broadleaves,}
u	diameter classes	{12,5 cm, 22,5 cm, ... , 127,5 cm, 137,5 cm+}

7.1.4 Variables

Notation	Definition	Unit
$F_{w,i,t}$	Volume of standing that may enter the industry of product w	m^3
$S_{w,i,t}$	Supply of composite products w in region i on year t	m^3
$LS_{w,i,t}$	volume of products w sold on domestic market in region i on year t	m^3
$X_{w,i,t}$	Volume of domestic products w exported abroad from region i on year t	m^3
$D_{w,i,t}$	Volume of domestic products w consumed by transformation industries in region i on year t	m^3
$\tilde{P}_{w,i,t}$	Price of composite products w in region i on year t	€/m^3
$P_{w,i,t}$	Price of domestic products in region i on year t	€/m^3
$S_{p,i,t}$	Volume of domestic products p produced by transformation industries in region i on year t	m^3
$D_{p,i,t}$	Demand of composite products p in region i on year t	m^3
$LD_{p,i,t}$	Volume of domestic products p consumed in region i on year t	m^3
$M_{p,i,t}$	Volume of foreign products p imported in region i on year t	m^3
$e_{w,i,j,t}$, $e_{p,i,j,t}$	exports of w (p) from region i to region j on year t	m^3
$\tilde{P}_{p,i,t}$	Price of composite products p in region i on year t	€/m^3
$P_{p,i,t}$	Price of domestic products p in region i on year t	€/m^3
$V_{u,i,g,e,t}$	Volume of wood for each domain (u,i,g,e,t)	m^3

7.1.5 Parameters

Notation	Definition	Unit
c_p	Unit production cost for products p	€/m^3
$b_{D_{p,i}}$	Armington specification parameter	%
$b_{S_{w,i}}$	Armington specification parameter	%
$P^*_{w,t}$	Selling price of products w produced in France and sold abroad	€/m^3
$P^*_{p,t}$	Price of products p imported in France	€/m^3
$C_{w,i,j}$, $C_{p,i,j}$	Unit transport cost of w (p) between region i and region j	€/m^3
$a_{p,w}$	input output coefficients : volume of product w to create one unit of product p	
$K_{p,i,t}$	Production capacity	m^3
$G(w)$	Forest inventory domains which standing trees may enter wood industry w	
ϵ_w	Price elasticity of supply of products w	
β_w	Elasticity of supply of products w regarding the inventory volume	
$\varphi_{w,i}$	Transformation elasticity between products w sold in France and products w sold abroad	
$\varphi_{p,i}$	Substitution elasticity between foreign products p and French products p	