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Modelling European Forest Products Consumption and Trade in a Context of Structural Change

Paul Rougieux

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par Paul Rougieux

Modelling European Forest Products Consumption and Trade in a Context of Structural Change

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Abstract-en

Forests in the European Union grow by 1.2 billion m³ per year. Half of this volume stays in the forest, in particular for sustainable forest management purposes. The other half flows into three industrial sectors: wooden material, paper products and wood energy. These industrial product flows are set into motion and paid for by diverse final consumers. Since 2000, consumption is undergoing important structural changes which cause large disturbances in material, paper and fuel flows. To predict the impact of these changes, economists model relationships between raw material supply, final products demand, prices, production and international trade. This thesis uses panel data econometrics to estimate parameters of empirical models.

An introductory chapter sets the policy context of forest resources and forest products of interest at a macroeconomic level. Then I review major forest sector models and I focus on issues encountered while estimating parameters of demand models. A second chapter investigates the potential impact of a trade agreement between the EU and the US on the forest sector. We found that total welfare would increase in the region of the agreement, in addition the agreement benefits more to consumers than to producers. Results show that third party countries are impacted by the agreement too, which highlights the importance of using a global trade model in analysing the impacts of the agreement. In a third chapter I estimate revenue and price elasticities of demand for forest products on a panel of European countries. I deal with non stationarity issues and estimate demand elasticities within cointegrated panels. I demonstrate that revenue elasticities of demand are lower than previous estimates from the literature. Simulations using these robust elasticities in a forest sector model, show a lower demand over a 20 years time horizon. In a fourth chapter, I analyse structural changes in paper products consumption. For this purpose, I use a panel threshold model to estimate the relationship between information technology use and paper products consumption: newsprint, printing and writing paper. I show how paper demand elasticities depend on internet penetration in the population. Thresholds occur once a majority of the population has access to the internet. After the threshold, coefficients between paper consumption and its explanatory variables revenue and price become smaller in absolute terms or even change sign. Based on projections of the number of internet users per country, paper consumption projections could be updated with this type of thresholds models. From a policy perspective, lower demand for graphics paper would free resources and make them available for innovative forest products and services.

Résumé en français

Les forêts de l'Union Européenne croissent de 1.2 milliards de m³ par an. La moitié de ce volume reste en forêt, notamment pour des raisons de gestion durable. L'autre moitié alimente trois filières industrielles: la filière matériaux, la filière papiers et la filière énergie. Ces flux de produits industriels sont mis en mouvement et financés par divers consommateurs. Or depuis 2000, la consommation change de régime, au point de perturber fortement certains flux de bois et d'impacter l'emploi et la balance commerciale du secteur. Pour prévoir l'impact de ces changements, les économistes modélisent les relations entre l'offre de matières premières, la demande de produits finis, les prix, la production et le commerce international. Cette thèse construit un modèle empirique à même d'évaluer l'impact de ces changements pour le secteur forêt-bois en Europe.

Un chapitre introductif définit le contexte des ressources forestières et des produits analysés au niveau macroéconomique. Puis je présente les principaux modèles en équilibre partiel utilisés pour les études prospectives du secteur forêt-bois. A partir d'un cadre général incluant la production et le commerce international, je détaille les problèmes spécifiques rencontrés lors de l'estimation des fonctions de demande. Un deuxième chapitre étudie l'impact potentiel d'un accord commercial entre l'Union Européenne et les États-Unis sur le secteur forestier. Nous avons trouvé que le bien-être total augmenterait dans la région de l'accord et diminuerait légèrement ailleurs. De plus l'accord est plus avantageux pour les consommateurs que pour les producteurs. Les résultats montrent aussi que des pays tiers sont impactés par l'accord, ce qui souligne l'importance d'utiliser un modèle mondial. Dans un troisième chapitre, j'estime les élasticités prix et revenu de la demande en produits forestiers sur un panel de pays européens. Je traite des problèmes de non stationnarité en panel et j'estime les élasticités au sein de panels cointégrés. Les élasticités de demande sont inférieures aux estimations précédentes dans la littérature. Ces élasticités robustes insérées dans un modèle secteur forêt-bois projettent une demande plus faible sur une période de 20 ans. Dans un quatrième chapitre, j'analyse les changements structurels dans la consommation de papier. J'utilise un modèle économétrique sur données de panel permettant d'estimer les effets de seuil dans la relation entre l'utilisation des technologies de l'information et la consommation de papier: papier journal, papier d'impression et papier d'écriture. Je montre comment l'élasticité de demande de papier dépend de la pénétration d'internet dans la population. Un effet de seuil a lieu lorsque la majorité d'une population a accès à internet. Après le seuil, les coefficients liant la consommation et ses variables explicatives (prix et revenu) diminuent en valeur absolue ou changent de signe. A partir d'une projec-

tion du nombre d'utilisateurs d'internet par pays, les projections de consommation de papier pourraient être mises à jour avec ce type de modèles à transition. Une plus faible demande de papier libère des ressources et les rend disponibles pour le développement d'autres produits et services forestiers innovants.

Une version longue de ce résumé est disponible en annexe A.

Contents

1. Introduction

Wood consumption in the European Union was estimated at 550 million m^3 in 2010 (Mantau *et al.*, 2010). With a population of 500 million inhabitants, each EU citizen consumes a little more than $1m^3$ of wood per year. A fundamental policy question is: will forest resources continue to match forest products demand in the future? In my research I analyse the demand side of this question. Various forms of investments contribute to sustain forest products supply over the long term. Forest owners invest in plantation, regeneration and thinning, while forest products industries invest in capital intensive machinery. Various agents invest in the forest sector, expecting that future demand will absorb their production and generate return on investment. Understanding long term changes in wood consumption is a key concern for private and public investors alike. These developments are also of interest to the natural resource research community at large; if they want to follow the most important renewable material in terms of consumption volume. Here a distinction must be made between renewable fuels and renewable materials. This thesis will mention the former but it will focus mostly on the material sector.

The present introductory chapter describes the context and policy questions which have led researchers to develop forest products models. Section 1.1 starts by giving an overview of how forest resources meet industrial demand. Section 1.2 introduces drivers of changes: public policies, mainly in the form of environment regulations and structural changes. On this basis I introduce models of the forest sector in 1.3. Subsequent chapters are based on research articles. The second chapter was published in Journal of Forest Economics, the third chapter is in revision in a general purpose economics journal. The fourth chapter was presented at a conference in Ulvön, Sweden and remains to be submitted.

1.1. Forest resources supply

An official definition of Sustainable Forest Management was provided by a 1993 Ministerial Conference for the Protection of Forests in Europe:

“the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems.”

Second Ministerial Conference on the Protection of Forests in Europe (1993)

This section illustrates challenges related to forest management. The goal of forest management has been to produce high value trees for high value solid wood products. High value solid wood remains important, but as we will see in sections 1.1.4 and 1.2, an increasing number of engineered wood products make use of small diameter trees and residues, in which the quality of the fibre is more relevant than the shape of the tree. This change of resource scale - from log to fibre - also impacts the economic importance of various coniferous and broad leaf species as well as forest management principles. Note that forest owners are careful of changing their management principles too quickly as consumption behaviour can change several times before a forest stand is mature for harvest. This wariness is especially warranted for long lived forest trees such as oak. The French forest of Tronçais for example was part of seventeenth century forest management strategy for boat production. Four centuries later, French navy boat are made of other materials but the Tronçey forest turns out to be a high quality source of oak for wine barrel production.

1.1.1. Sustainable Forest Management

The renewable nature of forest products is similar to agricultural products, except that rotation periods are much longer. Mature Norway spruce are harvested at 70 years and mature oak trees can be several centuries old when harvested. While farmers make investment decision for which they expect a return in their lifetime, forest owners make investments for which their expected return will benefit future generations. The long time scale means that long term demand projection are of interest for forest owners, even though projections are likely to be wrong. Forest owners are not profit maximizing in the usual sense of the term but rather invest over the very long term.

The nature of forest investments place them at the fringe of economic analysis. Investment decision are not necessarily made by rational agents maximising their utility. On the one side, forest investment decisions are to a large extent based on non-market values. On the other side, the sale of forest products remains the main provider of financial resources for forest owners. If decision making was a pendulum between two extremes, it would oscillate between protected forests which maximize non-market values and plantation forests which maximise market values. In between many alternative “integrated forest management” are practised by forest owners.

Forest management is not the purpose of this thesis, but if there should be only one distinction made between the various forest management principles it should be between plantation and natural regeneration. Between 1990 and 2015, the area of planted forest has been increasing from 4% to 7% of the global forest area (Payn *et al.*, 2015). Plantation owners select seedlings with a high potential to adapt the forest resource the industry’s need. Suitable in cases where the return on investment

is high, plantations are more profitable in areas where there is a high soil fertility and/or where plantation and labour costs are low. Natural regeneration is practised commonly as a lower cost alternative, it enables forest owners to adapt their investment to the existing natural capital. Natural regeneration and the related practice of continuous cover forestry are practised in broad leaved and coniferous forests in central Europe (Hanewinkel *et al.*, 2014) and can also be practised in Northern Europe (Axelsson *et al.*, 2007) as well.

Forest economics is particularly challenging because of the tremendous difference of time scale between economic cycles and forest growth cycles. The low correlation between the value of forest assets and the value of other conventional investments make forests an instrument of choice for portfolio diversification. Mono-species plantation are the most profitable type of management in the absence of risk, but mixed forests can also constitute risk prevention buffers in the investment portfolio of wealthy investors (Knoke *et al.*, 2005; Brunette *et al.*, 2014). Similar diversification strategies are also used by poor households in developing countries (Delacote, 2007) where forests and their products are seen as a safety net for difficult economic times.

Forest management is at the root of the oldest sustainability discourse. Indeed, “Nachhaltigkeit”, the German term for sustainability was used for the first time by Hans Carl von Carlowitz in his 1713 work “Silvicultura oeconomica”. Over time, societies have managed forests according to their perceived future needs. Forests today and in the past fulfil multiple societal needs: they are a source of renewable material and renewable energy. They provide ecosystem services such as: outdoor activities, biodiversity conservation, drinking water protection and CO_2 storage. Forests can be seen as a source of commodities and services, which decision makers seek to develop harmoniously. But policy interactions and conflicts are bound to occur as explained in section 1.2.1.

World governments agreed upon general sustainability principles during the Rio Declaration on Environment and Development (1992). Those general principles were put in place to guide economic development and were linked to national sovereignty and trade issues. In the forest sector, sustainability means that today’s forest owners harvest trees regenerated or planted by preceding forest owners. Sustainability principles are implemented in forest legislations to ensure that forestry activities can continue in the future. For instance, many countries have strong legislation that prevent the conversion of forest land to other land uses.

1.1.2. Industrial supply chain network

The biochemical process at the source of forest products is photosynthesis. In a sense, forests are a source of renewable solar based material for the industry. To illustrate imagine a typical forest tree transformed into different products by different sub-sector of the industry. The lower part of the trunk is transformed in sawnwood. The upper part is transformed in pulp for paper or in wood panels. The remaining

branches are used for wood energy purposes. Many different variations of this scenario are possible, the whole trunk could be used for a single purpose and branches could be left in the forest to maintain litter. This description could be refined almost indefinitely by talking about the multiple economic uses of all available tree species. But the main transformation remains from a natural resource to primary industrial products to final consumer goods. It is our goal to understand how consumer behaviour changes and how these changes can impact the forest sector. When consumers decide to purchase furniture, books or houses, their choices and preferences impact forest products consumption. But the variety of products involved make it impossible to study final consumer behaviour at the macroeconomic level. This is why I analyse the aggregated consumption of primary industrial forest products.

Forest trees are growing by a certain volume each year called the annual increment (on the order of 1.3 billion m^3 yearly in the EU¹). From this volume, 700 million m^3 stay in the forest and the rest is consumed by 3 industrial sectors: 300 million m^3 are transformed by the wood products industry, 100 Mm^3 transformed by the paper industry and 200 Mm^3 are burned to generate energy. Wood products flows are set into motion by final products consumers. While each sector requires different wood material qualities, there is considerable overlap and complementarity in the sourcing process of each industry (see also 1.1.2). Complementarity is evident in the case of sawmills which process a large part of the yellow flow representing the wood products industry. Round wood harvesting is a costly operation. It is generally less costly to re-use industrial residues as illustrated by the orange flow (Figure 1.1) going from the wood working industry to other industries. Reuse of co-products and recycling of used products greatly increase the material efficiency of the forest sector. Over time as recycling rates progress, more products can be created from the same amount of raw material.

Interesting as it may be from an engineering perspective, a picture of physical flows alone lacks a critical piece of information, namely prices. Indeed at each market stage, a producer and a consumer exchange a good only if they both agree on its price. In other words as long as a consumer is willing to pay more than what a producer is willing to accept. For each product, in each country, interactions between all consumers and producers can be represented by a classical market equilibrium illustrated Figure 1.8. I will come back to market equilibrium mechanisms in section 1.3.1.

Section 1.3 will later describe how forest management, the industrial supply chain and international trade are structured by several layers of market interfaces.

1.1.3. International Trade

The EU's forest products net trade (export volumes minus import volumes) is positive since the year 2000 as visible in Figure 1.2 based on data from FAOSTAT

¹Illustrated at the top of the wood flows in Europe Figure 1.1, based on Mantau *et al.* (2010)

1.1 Forest resources supply

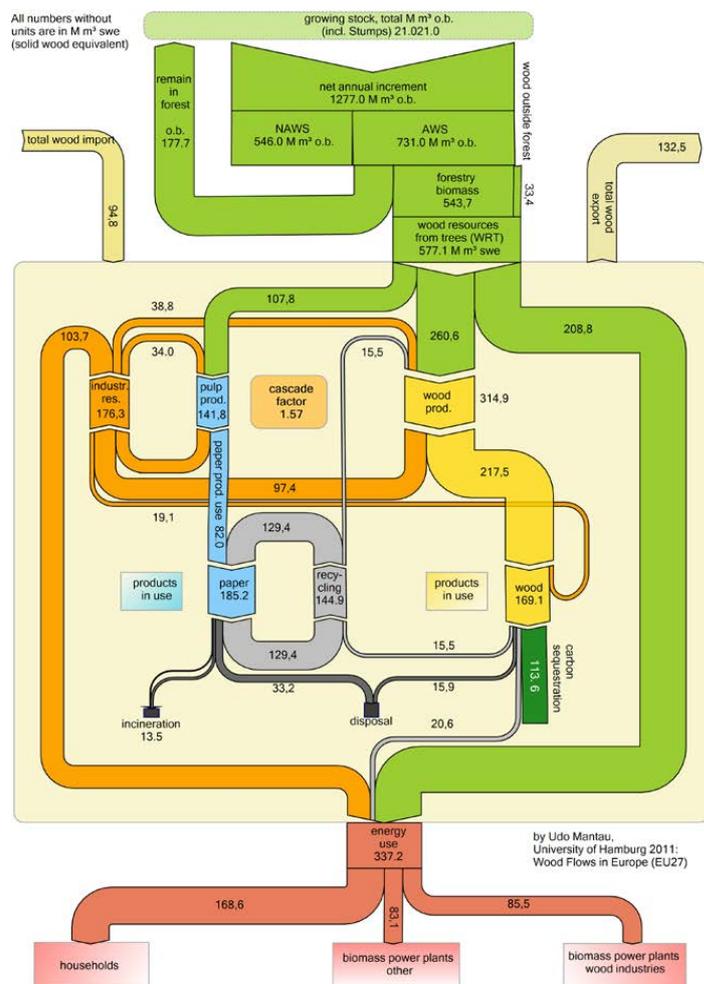


Figure 1.1.: Wood flows in the EU - Figure from Mantau 2012

(2016). Figure 1.2 hides wide disparities within European countries, some being net exporters while other are net importers. But overall, we can see that the EU has always been a net exporter of paper products. There was a trade deficit for sawnwood and wood based panels until 1995 and 2000 respectively but since then, the EU is a net exporter of those forest products. This may not be true for final products which are not represented here such as furniture.

Paper products and sawnwood have the highest trade volumes. Fuel wood which is a low value material tends to be consumed close to the place of production. A large proportion of it traded locally at the village or city level or consumed by those who harvest fuel themselves. In contrast in recent years, an increasing proportion of fuel wood has been traded internationally. Although there are exceptions, with the EU increasingly importing pellets from north America and Russia on the order of 3.8 million tons in 2012 (Johnston, 2016). This development is the result of a myriad of factors: European subsidies to renewable energy, and crisis in the North American

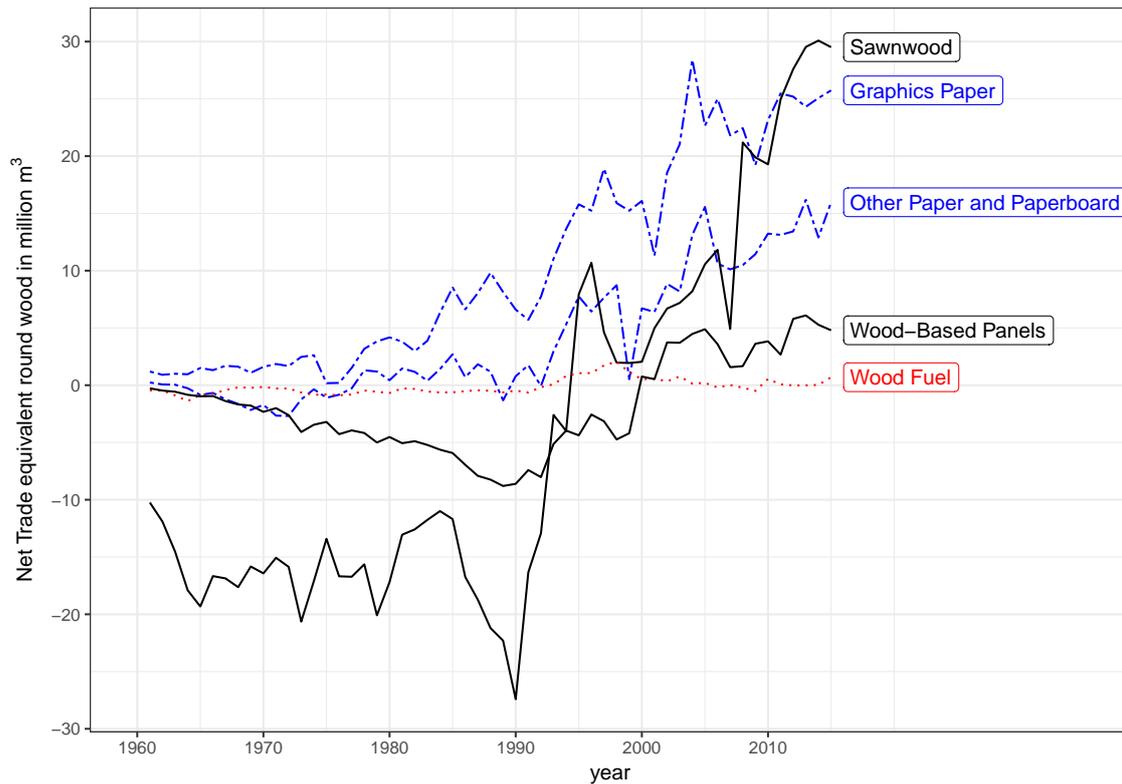


Figure 1.2.: Net trade of forest products between the EU and the rest of the world

construction sector leading to over capacity. If this combination of factors doesn't last, wood fuel trade between North America and the EU may decrease in the near future.

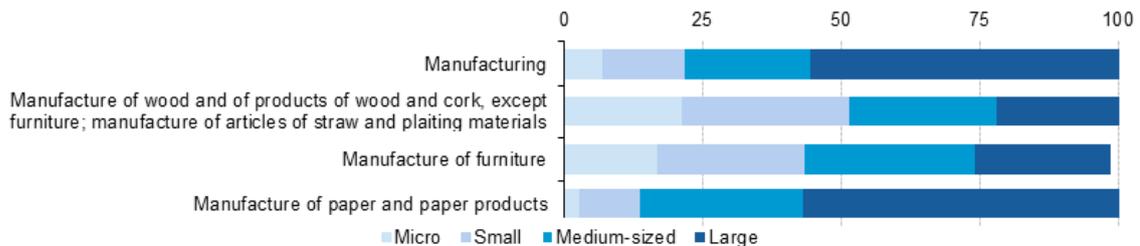


Figure 1.3.: Value added by enterprise size class, manufacturing (NACE Section C), EU-28, 2012 source: Eurostat, Statistics Explained

Most of the value added in the manufacture of wood products is generated in small enterprises (Figure 1.3). In the particular case of sawnwood, the number of small sawmills tends to decrease over time and large facilities produce an increasing share of total sawnwood production (Nilsson, 2001). Paper products are mostly manufactured in highly integrated, large facilities.

How important is trade to consumption? The share of import in consumption

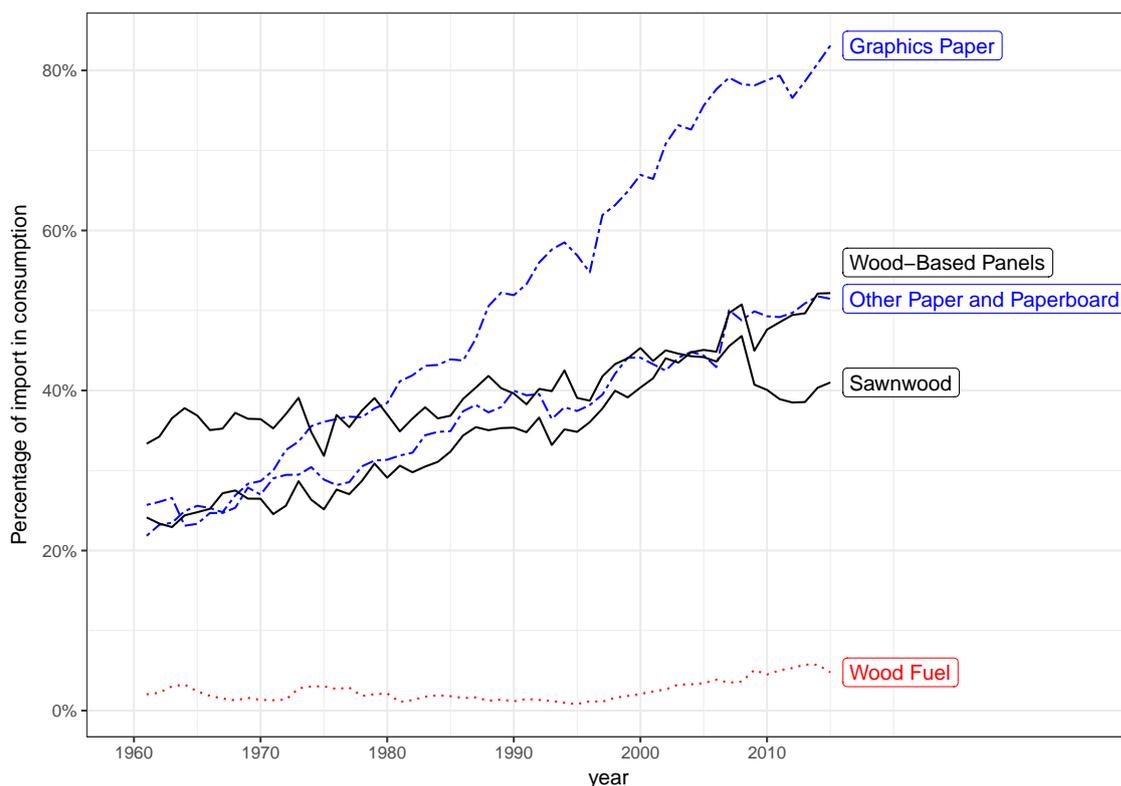


Figure 1.4.: Share of import in consumption

Figure 1.4 shows that before they reach a consumer, most forest products have crossed at least one border. And this proportion has been increasing over time. In particular paper products are traded more intensively with up to 80% of consumption coming from imported products. While approximately half of panels, sawnwood and packaging paper are imported.

1.1.4. Forest products consumption

Consumers who purchase furniture and books or renew their roof are ultimately consuming forest resources. Over time, the consumption dynamics of each of these products differ and co-evolve with complementary material and/or substitute material detailed in section 1.1.4.3.

Figure 1.5 shows a rough estimation of each products consumption measured by the volume of round wood that would be necessary to produce them. These estimates are a crude approximation: only four conversion factors (Table 1.1) were used to convert tons of paper and cubic meters of sawnwood, panels and fuel wood to a volume equivalent roundwood. The conversion does not take into account the fact that part of the raw material used in paper production comes from recycled paper. Paper recovery rate vary between 39% in Poland to 77% in Germany but utilisation

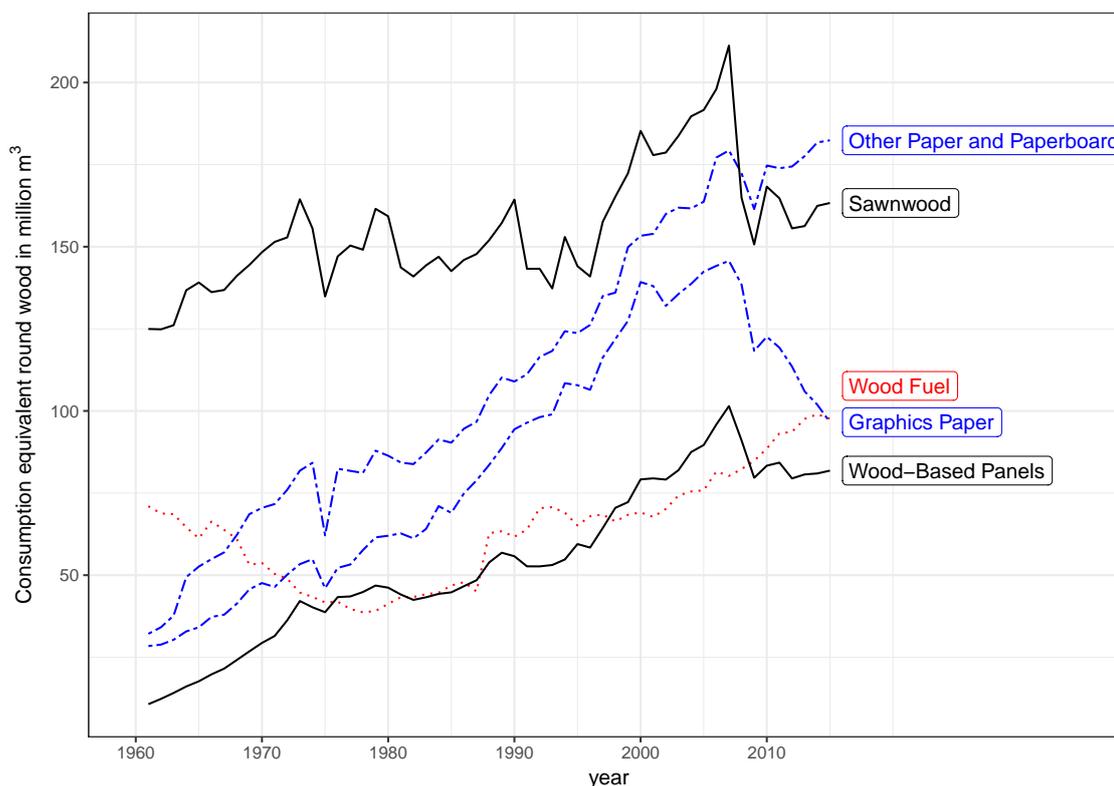


Figure 1.5.: EU forest products demand in volume equivalent round wood (based on FAOSTAT data and conversion Table 1.1)

rate (measured by the recovered paper consumption divided by paper and board production) vary widely by countries from 5% in Finland to 68% in Germany in 2008 (Hujala *et al.*, 2010). Similarly, sawmill residues are used in pulp, panels and fuel production. Besides, the recycling rate increases through time. One ton of paper consumed in 2010 leads to less roundwood harvest than it did in 1970. As a consequence, paper, panel and fuel wood volumes are over estimated in Figure 1.5. Although those volumes cannot be used for comparison with round wood production, they serve the purpose of showing the consumption of four secondary forest products on one graph.

Table 1.1.: Conversion factors to equivalent round wood based on UNECE-FAO (2010)

Product	Conversion factor	Unit
Paper and Paperboard	3.50	$m^3 \text{roundwood}/t$
Sawnwood	1.88	$m^3 \text{roundwood}/m^3$
Wood Fuel	1	$m^3 \text{roundwood}/m^3$
Wood-Based Panels	1.50	$m^3 \text{roundwood}/m^3$

Consumption generally grew over the last 50 years (Figure 1.5). The economic crises

of 1973 and 2008 impacted consumption of all products except fuel wood. Sawnwood consumption was rather stable throughout the period. But within sawnwood, the proportion of coniferous sawnwood rose while non coniferous sawnwood consumption was in constant decline. The apparent consumption of non coniferous sawnwood decreased by 50% between 1980 and 2015 in the EU 28 FAOSTAT (2016). Paper products and panel consumption increased throughout the period. It is interesting to see that sawnwood represented the largest share of consumption at the beginning of the period but represents only a small proportion at the end of the period.

The section below describes some of the issues related to the 4 major product groups analysed by macroeconomic models of the forest sector: Sawnwood, Wood Panels, Paper Products and Wood Fuel.

1.1.4.1. Sawnwood

Sawnwood products are used in two major markets: the construction and furniture industry. The construction sector uses sawnwood to produce joinery, roof structures, timber frame housing and glue laminated beams. Sawnwood requires high quality saw logs for its production. Compared with other biomass-based products, saw logs tends to be based on slow growing trees, require long term forest management leading to higher material costs. As a result raw material prices represent a much higher share of sawnwood prices compared to other forest products. In parallel value added tends to be low in sawmills, even if there are efforts to increase value added (Lähtinen and Toppinen, 2008; Brege *et al.*, 2010).

The capacity to sell co-products is essential for a saw mill profitability. Proportions vary widely between species and log diameters but on average, only a little over half the initial saw logs volume can be recovered in the form of sawn wood (Table 1.1). The bark, saw dust and flashes are available as co-products for paper, panel and fuel wood production. This type of integrated processes has been theorised as self-organized industrial symbiosis (Chertow, 2007). It is the process in which one industry's waste becomes the raw material for another industry (Frosch and Gallopoulos, 1989). In fact, for sawmill operators saw dust is not a waste, but they prefer to call it a "by-product". There is a lack of theoretical economic model on the reuse of by-products. Most forest sector model, even those which include multiple products do not consider the flows of by-products.

According to Döring (2012) sawmills are the main organisers of wood mobilisation in Germany. This position as a major node in the supply chain responsible for the harvesting decision is likely to be similar at the European level. Most of the volume going through the first yellow node "wood products" illustrated Figure 1.1 is processed in sawmills.

1.1.4.2. Fibre-based products

Wood-based panels are made of lower value raw material such as forest residues and can thus be produced at lower price than solid wood products (Rivela *et al.*, 2006, 2007). Over the last fifty years, the aesthetic of wood based panels improved so that consumer shifted their preferences from solid wood to fibre-based materials. For example the vast majority of furniture and floor or wall panelling are now made of particle board or fibre board, instead of solid wood.

According to Figure 1.1 (Mantau *et al.*, 2010), by 2010, wood fuel represented 200 million m^3 or 40% of the total wood resources consumed in the EU. The figure is slightly lower but in line with the FAO data presented Figure 1.5. Another 100 million m^3 wood residues should be added to this amount. About half of the European consumption is burned by household, often in low yield chimneys or ovens. A quarter is used - in the form of wood residues - by the forest products industry to generate electricity and heat for wood drying processes. Kiln drying is by far the highest energy input in sawnwood production (Ramage *et al.*, 2017). The remaining quarter is burned in other biomass power plants, mainly district heating facilities and potentially electricity power plants.

Biomass is a bulky, material with low value per unit of volume, therefore transport costs represent a large proportion of up to half the cost of wood fuel (Shabani *et al.*, 2013). Besides, profits from the sale of wood biomass help finance thinning operations necessary to enhance the growth of high value trees. Further down the value chain, sawmill by-products are used for panel production or energy generation. In fact saw mills and pulp mills are large producers of renewable energy. For these reasons, the forest-based sub-sectors: sawmill, paper mill, panel production and wood energy sector are largely interdependent for their raw material supply. Because of these inter dependencies, illustrated at the European level Figure 1.1, analysing the competition between sub-sectors is complex. In a normal market state, when there is sufficient supply, lower value products go to the energy sector and there is no competition between material and energy uses of wood. But when demand and prices rise high enough, fuel wood supply start to compete for raw material with panel and pulp products.

Compared to other forest products, European fuel wood consumption (Figure 1.5) has a very different dynamic. Fuel wood consumption decreased through the 1970ies, before rising again after the 1990ies, and it wasn't impacted by the 1973 and 2008 energy and financial crises. An important growth factor after 2000 has been the development of biomass-based district heating. Investments in biomass-based heating facilities were stimulated by public policies in the frame of the EU 2020 renewable energy Directive (European Parliament, 2009). I will come back to energy policies later in section 1.2.1.1.

1.1.4.3. Substitute products

Besides forest based products, consumers can chose among substitute products made from a range of alternative materials. For example, steel and concrete roof constructions are an alternative to wooden roof construction. In the furniture sector, various metals and plastics materials are used as an alternative to build chairs and shelves. In packaging, corrugated cardboard can be replaced by plastic material. In the publishing industry, electronic media such as tablets can replace paper-based books, I will expand this specific topic in chapter 4. For heating purposes, diesel fuel and natural gaz are alternatives to wood fuels.

It is clear that new material developments in the metal, concrete, plastic or composite sector can displace wood usage, but the opposite is also true as new wood usages can displace alternative materials. Substitution can also happen between different products within the forest sector. The literature on forest sector models rarely includes non-forest products in its modelling frameworks.

1.2. Drivers of long term change

This section describes policies and technological changes that influence forest products supply and demand. The interaction between various policies mean that there is a need for reliable prospective tools, in order to plan forest management for the long term future. Given the wide range of issues at stake, the analysis will draw from a range of interdisciplinary methods.

1.2.1. The impact of public policies on forest products supply and demand

Forests provide a habitat for animal species and a place for human leisure activities. Environmental services such as animal habitat and landscape beauty do not have a market valuation. But their values are far from negligible, indeed several studies estimated that the value of forest recreation (Zandersen and Tol, 2009) for example can be as high as the value of timber production. Environmental policies take into account the increased economic value generated by recreation amenities. As they potentially reduce the amount of wood available for harvest (Verkerk *et al.*, 2008), forest protection policies are meant to interact with the industry. Forest policy is a balancing act between economic, environmental and social constraints. This section highlights some of the public policies that affect the forest sector and the interactions between them.

1.2.1.1. Renewable energy and CO₂ emissions policies

Even though the major part of the wood consumption volume globally is used for energy purposes, by far the major part of its value is generated from wood-based products. One of the purposes of this thesis is to analyse policies influencing material uses of wood. But because they are based on the same material, renewable energy policies have a strong influence on the forest sector. Biomass is the first source of renewable energy in Europe. Indeed biomass and renewable waste account for two thirds of the primary renewable energy production in the EU-28 in 2013 (EUROSTAT, 2015), much higher than hydropower and wind combined. It should be noted that wood biomass represents only a part of total biomass consumption. Used mainly for heat production and to a lesser extent for electricity generation, biomass consumption has continued to increase in recent years, though at a slower pace than solar and wind. Increased consumption has been incentivised by EU renewable energy targets which encourage alternatives to fossil fuels (European Parliament, 2009). Yet the increased use of biomass in the renewable energy mix has been criticized by the forest sector for over emphasising the use of fuel wood at the expense of material uses of wood (Mantau *et al.*, 2010). On the other hand, biomass co-production is essential to the profitability of forest sector activities.

For the purpose of maximising emissions reduction, different levels of wood resource use should be distinguished. A meta analysis of twenty studies shows that on average 1 ton of carbon used in wood products creates an emissions reduction of 2 tons of carbon (Sathre and O'Connor, 2010). Wood products are a valuable means to reduce CO₂ emissions when used in a building or furniture. In fact, when looking at avoided emissions, wood processing is more efficient than alternative materials such as plastic, aluminium, steel or concrete. Some have concluded that wood energy should be used as a last resort, at the end of life of its valuable material use.

Climate change mitigation option within the AFOLU IPCC 5th assessment 3rd report on mitigation mention changes in consumption behaviour as a mitigation option:

“Demand-side options (e. g., by lifestyle changes, reducing losses and wastes of food, changes in human diet, changes in wood consumption), though known to be difficult to implement, may also play a role (Section 11.4).”

1.2.1.2. Biodiversity conservation and forest recreation policies

Biodiversity consideration might seem remote from the production imperatives of the forest sector, they are nonetheless central to the integrity of forest ecosystems. In this section I would like to briefly describe the trade-off between biodiversity conservation and intensification of forest management practices. Although the link with forest products consumption may seem tenuous, biodiversity protection issues could participate in the environmental consciousness of forest products consumers.

The trade off between production intensification and biodiversity protection is decided upon by public policies. Policy answers to this trade-off can lead to several outcomes on an axis with intensified harvesting on the one side and complete protection on the other side. Plantation and short rotation coppices being the most intensive types of management. Plant and animal diversity are high on naturally regenerated forests with mixed species and they are low on mono-species plantations. In general, the low environmental impact of forest management practices mean that commercially managed forests harbour biodiversity. There are several degrees of biodiversity importance, and the methodologies for assessing economic impacts on biodiversity are still in development. It is clear that private and public forests are important elements in the connectivity of protected national parks. Together, all forests - with various degrees of harvesting activities within them - harbour the major part of continental biodiversity (Myers *et al.*, 2000). Another important source of policy interest linked with animal presence in western European forests is the browsing by animals such as deer. Over browsing tends to reduce tree species diversity, although the effect on tree species dispersion are not fully understood Gill and Beardall (2001).

Forest structure also contribute to the quality of the landscape for recreation purposes such has hiking and cycling. Consumer preferences for specific landscapes has indirect measurable market impacts on tourism and housing prices for example. Surveys evaluate how some consumers have a preference for mixed forest stand in comparison to mono-specific plantations (Abildtrup *et al.*, 2013; Nielsen *et al.*, 2007).

Countries vary greatly in the way they have built forest regulations to deal with biodiversity related trade-offs. Some have set aside part of the forest area for complete conservation and allowed intense management in the remaining areas. This is the approach taken in countries such as the USA and New Zealand. European countries on the other hand have taken an integrative approach, where forest management integrates biodiversity conservation principles (Bollmann and Braunisch, 2013). Such management principles are called multifunctional: they should achieve the joint purposes of wood production, biodiversity conservation and recreation in the same forest. Additionally, increased forest protection in developed countries can lead to potential leakage and forest degradation in other countries.

Overall, forests role as biodiversity habitat contributes to the image of forest products as environmentally friendly products. Consumers certainly do not have a direct influence on forest management, but they could have an indirect influence by shifting to certified products. Indeed the Forest Stewardship Council (FSC) certification for example requires harvesting operations to set aside some trees for biodiversity purposes.

1.2.1.3. Forest certification

In the mind of a consumer, forest products convey two contradictory images both affecting nature in radically opposite ways. Consumers are torn between the negative image of deforestation and the positive image of a renewable natural product. In the absence of certificate of origin, a final consumer cannot possibly know if the forest from which a wood product came from was managed responsibly. In a market where information on sustainable practices is lacking, industries which do not respect environmental and social standards have an unfair competitive advantage. To address the issue of unsustainable practices, civil society and the industry created a new market for certified products. Certification schemes can be assimilated to brands, used to convey a quality signal directly to final consumers. This demand driven approach is based on marketing theory and the hypothesis that consumer preferences are concentrated on brands (Fournier, 1998). In a mature market where diverse products are available, the quality of a product is difficult to evaluate and brands acts as a quality signal. Consumers don't need to perform a quality assessment but make their decisions based on the label attached to a product (Cochoy, 2007). Other factors such as social prestige also play a role in the way customers establish a relationship with a brand (Vigneron and Johnson, 1999).

Wood products are one of the few natural resources that undergo certification and chain of custody on an international level. Certification has been encouraged by a different social acceptability of wood compared to other materials in buildings. Indeed what has become acceptable requests concerning wood material remains hard to imagine for other construction products. A certification of the sustainable origin of concrete or steel is not imaginable. In contrast, requirements for certified timber have become common place, especially for high value products or in the case of public procurement. Such is the contrast of the public image of wood as both a highly desirable material and a despised material connected with deforestation issues. Certification schemes such as the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) clearly label products that are the outcome of sustainable forest management. If enough consumers buy certified products, reduced demand for uncertified products will create an incentive for more forest-based industries to get certified and to eliminate questionable wood sources in their supply chains. Forest certification has seen a widespread adoption for example in the packaging and printing paper sector and to a lesser extent in the furniture sector. As a result of their market power, industry owning large consumer brands can gain policy influence and become important decision makers in forest products markets. But such consumer driven policies have shown limits with some considering they largely failed to change consumption practices (Haener and Luckert, 1998). In addition, Rametsteiner and Simula (2003) point that certification has been mostly adopted in the temperate zone and that its stated aim to reduce deforestation cannot be achieved as long as certification has such a low penetration rate in tropical countries.

Certification is seen as a way to increase awareness for sustainable forest management. Some commentators have felt that the high hopes placed in voluntary certification scheme have not been reached in practice and that other more stringent means have to be used against the industries that practice unsustainable wood harvesting.

1.2.2. The impact of structural changes

Technological progress has an effect both inside the forest sector and outside the forest sector. Technological progress within the forest sector leads to the creation of new products and new markets. In parallel, technological progress outside the forest sector leads to the substitution of forest-based products by alternative materials. In addition substitution also happens inside the forest sector itself. For example, particle and fibre board have increasingly substituted solid wood in the furniture industry over the the past forty years. Their consumption volume has grown indeed over 2% annually. In parallel non-coniferous sawnwood consumption decreased dramatically over the same period.

The impact of technological progress on wood products consumption can be illustrated with two examples. First, the development of panel making technologies in the 1980ies led the furniture sector to switch gradually from solid-wood to panel based production. Second, development in light frame wood construction and glue laminated beam technology lead roof making from traditional timber structures to light frame construction and then to engineered wood products. Finally, the impact of technological progress on paper products consumption will be further detailed in chapter 4.

1.2.2.1. Composite material and wood fibre

Wood is a natural material composed of various polymers: cellulose, hemicellulose and lignin. With the help of mechanical and chemical processes, individual constituents can be separated and re-assembled in new composite materials. For example cellulose can be chemically transformed in a viscose polymer to produce synthetic fabric used in clothes. The viscose process is not entirely new since it was developed in the nineteenth century already. But bio-refineries have recently seen industrial scale development in Nordic countries. With time, the transformation of wood fibres in new composite materials becomes more cost effective and possible on a large scale.

Forest-based materials are chosen over substitutes for several reasons, e.g. economic, aesthetic or/and cultural. Wood may be the cheapest material for a given purpose or present intrinsic structural qualities which cannot be easily reproduced with substitutes. For reasons of cost but also of structural strength, all major German car manufacturers use biomass-based composite panels in car production (Jawaid and

Khalil, 2011). Wood furniture and interior design are deeply embedded in our culture, because wood was an important construction material in the pre-industrial era. In the next section 1.2, we will show how the development of multi storey constructions using forest based materials demonstrates the growing role this material can play in modern construction.

Observing aggregate demand at the country level means observing the sum of two opposite development paths: forest-based products being displaced by their substitutes in some markets and forest-based products increasing market share in other markets.

1.2.2.2. Wood construction scenarios

Technological improvements in building material lead to new uses of wood in the construction sector. These developments can be illustrated by 3 major technological advances, in chronological order: glue laminated beams, pre-fabricated buildings, multi storey constructions.

Gluing techniques enables to overcome limits in length and thickness of the natural wood material. Sawn timber obviously cannot be longer than the log from which it was cut, roughly a maximum of 10m. Beam thickness is also limited for proper drying to occur, roughly a couple of centimetres. Gluing hundreds of small boards together makes it possible to build beams 1 meter thick, reaching several dozens of meters in length. Glue laminated beams can be used to replace wood beams in traditional housing construction or in large public buildings such as the roof structures of Olympic swimming pools, airport halls or even highway bridges Ramage *et al.* (2017).

Pre-fabricated buildings are made of wall and floor components prepared in a factory and assembled on the construction site. The goal is to achieve economies of scale by assembling complete wall panels with integrated windows, insulation material, interior and exterior plaster on an automated production line. Economies of scale help to reduce costs. The cost of wood material remains higher than that of concrete, but a prefabrication system provides shorter construction time and other benefits such as improved insulation. This technique has found a small but significant market share in private housing and is also used in larger office buildings.

Multi-storey buildings made out of wood build upon the 2 previous technological advances. Indeed, glue laminated beams are used extensively in multi-storey buildings. And construction methods draw heavily from pre-fabricated building construction techniques. Hurmekoski *et al.* (2015b) consider that multi-storey wooden construction could develop up to a 5% market share in densely forested countries such as in Scandinavia. However the adoption of these techniques will take a long time in the whole of Europe because building codes and regulations are slow to adapt to new construction techniques. In any case, the development of multi storey constructions will increase the consumption of sawnwood and wood panels. It was estimated that

if wood-based multi story housing gains a 10% market share in Germany, it would increase sawnwood demand by 1.5 to 2 million m^3 Pöyry (2016). Eriksson *et al.* (2012) integrated four different models to simulate potential development scenarios of multi-storey wooden construction. Their simulations show how a moderate increase in wood construction would contribute to reduce CO_2 emissions without affecting the forest sector. Eriksson *et al.* (2012) also simulated more extreme scenarios where sawnwood consumption would reach $1m^3$ per capita in Europe, but these scenarios led to drastic price increases, pushing models outside of their usual range of application.

1.2.2.3. Information Technology and Paper products scenarios

Since the mid 1990ies, a decline in newsprint consumption was observed in the United States and in other countries. Hetemäki (1999) emitted the hypothesis that this decline was due to the rise of information technology. But there was little data at the time to support this hypothesis. Similar to above developments, there is yet too little data to analyse composite wood products and multi storey construction impacts on a macroeconomic level. However additional data for the paper market which has accumulated since the work of Hetemäki (1999) 20 years ago shows a newsprint consumption decline in a large number of countries and a similar decline in the demand for printing and writing paper. Chapter 4 provides a detailed account of studies that have attempted to add new explanatory variables - related to Information Technology - that could explain the structural change. I contribute a new approach by using information technology as a threshold variable to explain the non linearity in paper demand.

1.3. Forecasting of wood-products markets

To make informed decisions, policy makers and investors are interested in demand and supply forecasts. A simplistic forecasting method would consider for example that linear trends of the past continue in the future. But trends tend not to continue for ever and when they change, numerous alternative future scenarios appear. Then to generate realistic scenarios, it becomes important to understand patterns of relationship between consumption and other relevant macroeconomic variables. For example a shock on final products demand will impact market prices and production. Other shocks on raw material supply will impact international trade flows. To understand these relationships, forest economists have used Samuelson's theories (1952) on the equilibrium between demand, supply and international trade. Such models provide policy relevant simulations when changes are expected in the market.

The following section will describe similarities and differences between a few global and national forest sector models. Then I will describe the structure of a dynamic-recursive partial equilibrium model to prepare some context for chapter 2 and es-

pecially describe how assumptions on demand are an integral part of forest sector models. Finally I will describe some of the estimation issues related to demand models to provide elements of context for chapters 3 and 4.

1.3.1. Approaches to forest sector modelling

This section compares a selection of Forest Sector Models (FSM). I selected 2 global models and 3 national models as examples to illustrate differences in forest sector modelling approaches. The Global Forest Products Model - GFPM (Buongiorno *et al.*, 2003) and the European Forest Institute's Global Trade Model - EFI-GTM (Kallio *et al.*, 2004) have a global scope. These are complemented by models with a national scope: the French Forest Sector Model FFSM (Caurla *et al.*, 2010), the Model of the Finnish Forest Sector - SF-GTM (Ronnala, 1995) and the Forest and Agricultural Sector Optimization Model - FASOM (Adams *et al.*, 1996), focused on the United States. Other forest sector models are currently in use, but for a large part they rely on similar theoretical background. For example the Norwegian model Norfor (Sjølie *et al.*, 2011b) starts with a similar approach to FASOM. More information on all forest sector models, including past developments is available in Buongiorno (1996), in Caurla (2012) and in Latta *et al.* (2013). Each of the following paragraphs focuses on one of these five differences: perfect/imperfect foresight, differences in supply models, differences in product manufacturing, differences in demand models, differences in trade elasticities.

A major difference between forest sector models concerns the agent's perception of the future. Model agents can know all future periods and have perfect foresight, or they can be myopic about the future and have imperfect foresight. In a perfect foresight model, agents maximise their surplus over the whole time horizon at once, a process called inter temporal optimization. This is implemented in the FASOM and NorFor models. In contrast, an imperfect foresight model has a static phase, in which agents maximise their surpluses for the current year only (more details in 1.3.3 below). Then comes a dynamic phase where demand and supply are shifted according to exogenous variables. And then comes a static phase again, and so on, in a recursive manner. Such dynamic recursive models are implemented in GFPM, EFI-GTM, SF-GTM and FFSM. Interestingly, Sjølie *et al.* (2011a) compared two Norwegian models, one with perfect foresight and one with imperfect foresight. They show that each model type has its own benefit. Recursive dynamic FSMs are better suited to analyse medium term market shocks while inter temporal optimisation FSMs are better suited to analyse long term silvicultural practices.

Raw material supply is modelled very differently in the various forest sector models. First, there are differences in products included as illustrated Figure 1.6. GFPM includes only one category of roundwood, while other models distinguish between pulp wood and saw logs. FFSM and FASOM further distinguish between coniferous and non coniferous logs and SF-GTM even distinguishes between specific tree

species. Second, on the time dimension, forest resources dynamics can be computed using either a simple rate of growth or a more detailed biophysical model. Simple growth rate and supply elasticities are used in EFI-GTM and in GFPM (formulated in 1.3.3). For example in GFPM, the rate of growth of the forest stock is calibrated to fit available historical data. Biophysical models provide more refinement by simulating tree growth. At each period, such models typically switch a certain volume of tree from one age class to another. Harvesting decisions are made through maximising the net present value of the returns from management activities. FASOM distinguishes tree age classes, ownership classes (Industry/other private), forest types (softwood/hardwood), site productivity, management intensity, suitability to transfer forest land to agriculture land. Data is grouped in nine US regions or groups of states. In each region, a unique combination of these classes is called a stratum and contains a certain wood volume. At each time period, a given stratum can be left to grow or it can be harvested. Additionally harvested strata can be changed to agricultural land use. Using a similarly notion of strata, FFSM simulates 10 age classes, 22 French regions, 2 species and 3 management intensities in the biophysical part of the model.

The number and nature of products manufactured also differs. Some models include primary products only, while other models include both primary and secondary transformed products. The former case is further detailed in the demand paragraph below. For the later case, quantity manufactured are typically determined by an input-output matrix which describes what volume of input product A is necessary to produce a certain amount of output product B. Those input-output coefficients are calibrated on historical or base year data. The manufacturing processes are illustrated by the arrows in Figure 1.7. GFPM also implements manufacturing rate of changes by which the input-output coefficients change over time, to represent technological progress. Other models can use various scenarios of future technological change and investments affecting production capacity. FFSM and SF-GTM include more final products than GFPM. FFSM distinguishes for example between coniferous and non coniferous sawnwood. In addition SF-GTM distinguishes between coniferous and non coniferous sawnwood and plywood, and different grades of printing and writing paper.

Final product demand depends on which products are considered in the manufacturing part of each model. FASOM for example includes only primary products, but the model does distinguish between different log qualities according to their industrial destination. In FASOM, consumption of saw logs and pulp wood is limited by the capacity of the consuming industries. Capacity can be purchased and depreciated endogenously. GFPM, FFSP, SF-GTM models which deal with secondary product manufacturing can use demand function where consumption depends on revenue and prices. These demand functions will be dealt with in extensive details in section 1.3.4. Demand scenarios can also be made dependent on other variables as necessary.

An additional difference concerns the substitutability between national and foreign

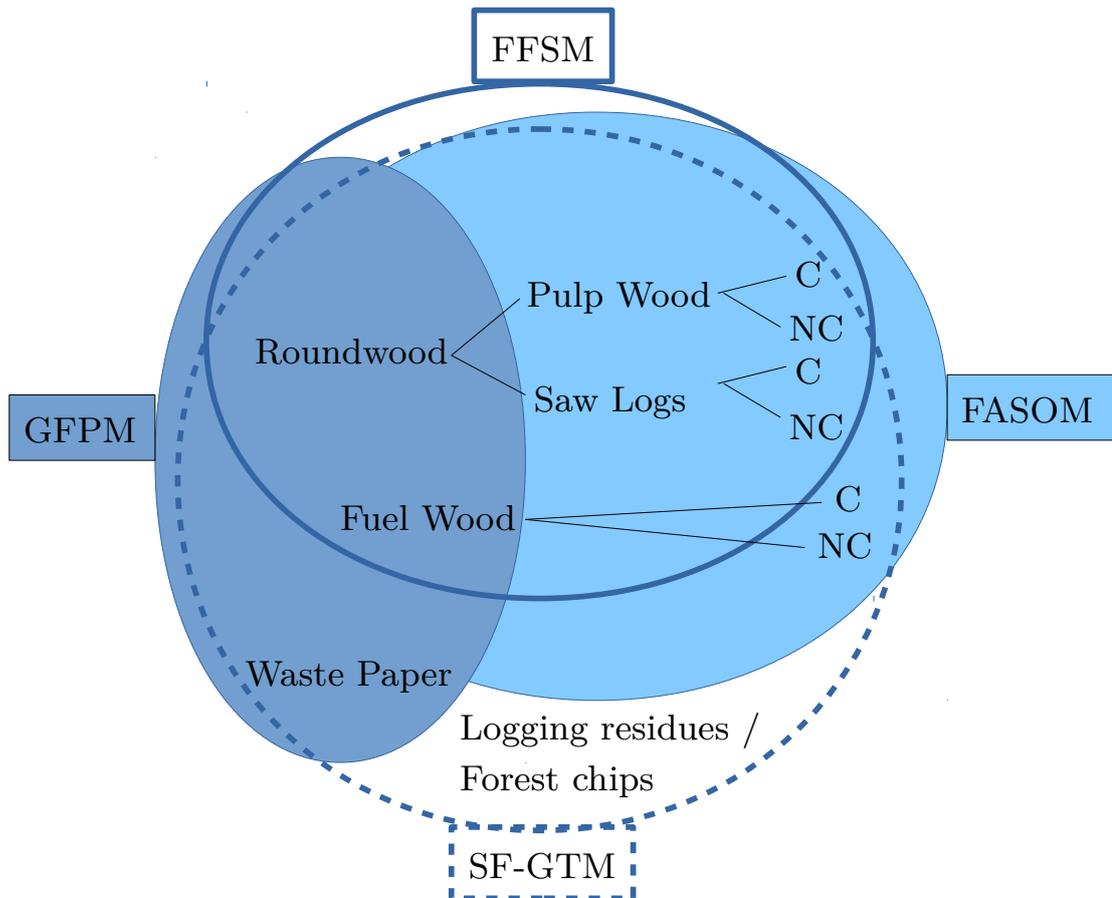


Figure 1.6.: Primary products included in various forest sector models

Figure note: C = Coniferous, NC = Non-Coniferous.

goods. Most models make the hypothesis of perfect substitutability. In that case demand elasticities are the same for domestic and foreign products. But the FFSM implements Armington elasticities where demand elasticities for foreign products are different than those of domestic products.

1.3.2. Applications of forest sector models

In recent years, many applications of forest sector models have focused on climate-change mitigation related scenarios. A small number of studies analysed other issues such as the impact of technological change on material efficiency, illegal logging and trade issues. This section give an overview of the interlinked issues which have been analysed by FSM.

Climate change mitigation scenarios revolve around three strategies: storing carbon

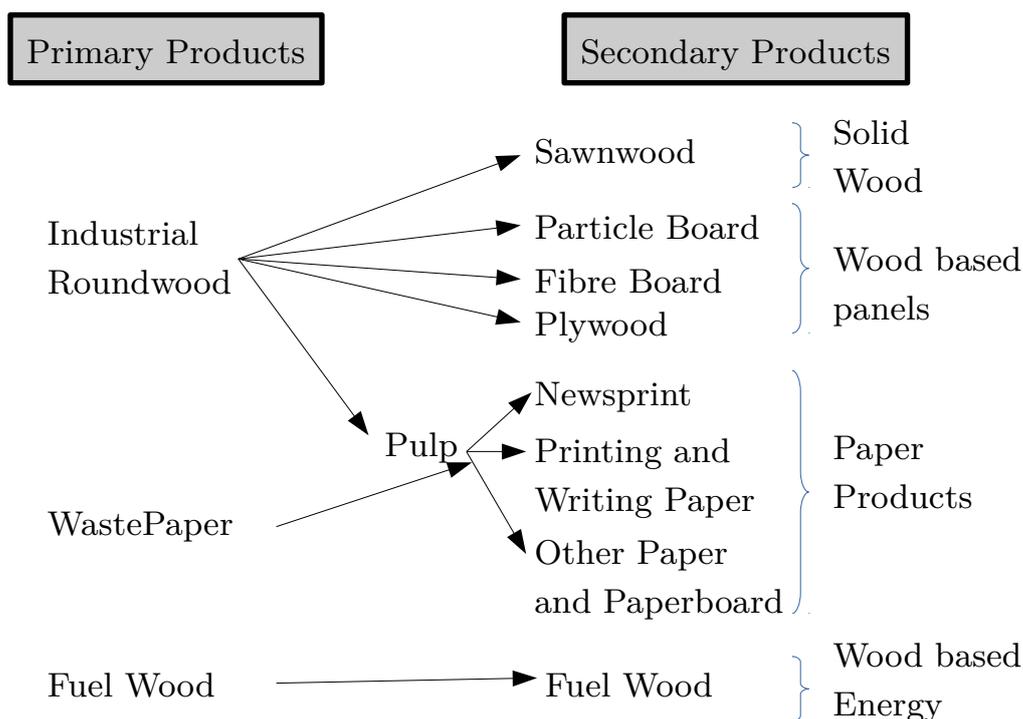


Figure 1.7.: Production of secondary products in the GFPM

in forests, substituting fossil fuels with biomass or substituting energy intensive construction materials with wood products. If pushed too far, these scenarios can lead to conflicting objectives with one another. As a result, the 3 strategies are the subject of intense policy debate in many countries. Forest sector models provide tools to compare the potential effects of various strategies in one consistent framework. Kallio *et al.* (2016) compared the mitigation potential of Finnish forests until 2050 by coupling the SF-GTM market model with a biophysical model. Their results highlight the importance of forest sinks to mitigate carbon emissions, while also pointing to the limits of sinks. Stored CO_2 will be re-emitted at the tree's end of life. But for the most part storage and substitution strategies have mutually reinforcing objectives. Lobianco *et al.* (2016) investigate the mitigation potential of French forests. They use FFSM to analyse and compare mitigation potential in forests to the potential in the market. They show that lower market prices favour sequestration and that higher market prices favour substitution but “not enough to compensate for the losses in sequestration”. However higher harvesting revenue may encourage forest owners to change species composition needed to adapt their forest stands to future climate conditions. In passing these authors mention the imperfect substitutability between the slow domain and the fast domain of carbon emissions (Ciais *et al.*, 2014).

Biomass emissions belong to the fast domain, where CO_2 emissions are eventually compensated by the CO_2 absorption in plant growth. While fossil fuels belong to the slow domain, where the rate of CO_2 emissions accumulating in the atmosphere cannot be fully reabsorbed in any biophysical reservoir.

On the energy demand side of the policy analysis spectrum, forest sector models can be used to simulate increased demand for fuel wood. Johnston and van Kooten (2016) simulate a doubling of the EU pellets consumption and its impact on the global forest sector. Rising pellet consumption leads to price increases for wood-based panels and pulp and a price decrease for sawnwood. Buongiorno *et al.* (2012) simulate the impact of increasing biomass demand under IPCC scenarios, a high biomass demand scenario would lead to increased fuel wood prices reaching those of industrial roundwood by 2030. Such a scenario would lead to diversion of roundwood into fuel wood, but it is sensitive to price developments in other energy sector.

Efficient resource use is another policy relevant aspect that can be analysed with forest sector models. Changes in material efficiency, in other words, the amount of raw material needed to produce a secondary product are typically studied at the firm level. But Buongiorno and Zhu (2015) shows that these changes can be analysed at a macroeconomic level by using the input output matrix mentioned below (coefficient a_{ikn} in equation 1.6). The long term decrease in input-output coefficients illustrate how improved material efficiency can be measured at the macroeconomic level too.

Concerning certification of sustainable forest management, Schwarzbauer and Rametsteiner (2001) show that the effect of forest certification would lead to modest changes on the European forest sector. The resulting increase in prices would affect sawmills more than paper and panel products. In developing countries, illegal harvest of forest products remains another important policy issue. Li *et al.* (2008, based on GFPM) estimate how an elimination of illegal logging would affect forest products markets. If other wood sources (mostly from developed countries) replace illegal sources their results show that world prices would increase. The net effect would be an increase in global wood stock. In another study related to the implementation of an EU policy aimed at reducing illegal logging, Moiseyev *et al.* (2010, based on EFI-GTM) simulate the effect of expanding Voluntary Partnership Agreements between harvesting countries and the EU. The model shows similar effects of increased production in developed countries and increased prices.

1.3.3. Details of a partial equilibrium model

The Global Forest Products Model (Buongiorno *et al.*, 2003) alternates a static phase and a dynamic phase. In the static phase, a market equilibrium is computed for a given year t . In the dynamic phase, supply, production and demand are shifted to new values for year $t+1$. Then, the market equilibrium is computed again in year $t+1$ and so on. Such models are called dynamic recursive. The section below briefly describes the market equilibrium and the dynamic market shifts to illustrate how

price and GDP elasticities are the a the heart of Forest Sector Models. Formulations below describe the GFPM specifically, other partial equilibrium models such as EFI-GTM, FFSM and SF-GTM may differ significantly in the formulation of demand and supply functions and in the scope of products included.

1.3.3.1. Static market equilibrium

Based on the theory of spatial equilibrium (Samuelson, 1952), in a given year, the market equilibrium can be computed by maximising producer and consumer surplus in the following objective function (Buongiorno *et al.*, 2012):

$$\max \left(\sum_{i,k} \int_0^{D_{i,k}} P_{ik}(D_{ik}) dD_{ik} - \sum_{i,k} \int_0^{S_{i,k}} P_{ik}(S_{ik}) dS_{ik} - \sum_{i,k} \int_0^{Y_{i,k}} m_{ik}(Y_{ik}) dY_{ik} - \sum_{i,j,k} c_{ijk} T_{ijk} \right) \quad (1.1)$$

Where i and j are countries, k are products, P are prices, D is the demand, S the raw material supply, Y the quantity manufactured, m the manufacturing cost, T the quantity transported and c the cost of transportation. 1.8 illustrates how the objective function maximises the area between the demand and production curves. A product k is either supplied from the forest or manufactured by the industry, both cases are illustrated by a similar producer surplus. In other words, the word “production” in 1.8 could be replaced either by “supply” or by “manufacture”.

The global static equilibrium 1.1 is based on the following representation of four market agents: demand D , supply S , manufacture Y and trade T . First comes a demand function:

$$D_{ik} = D_{ik}^* \left(\frac{P_{ik}}{P_{ik-1}} \right)^{\beta_{pk}} \quad (1.2)$$

where β_{pk} is the price elasticity of demand for product k and D_{ik}^* is the demand calculated based on the previous year’s price, using equation 1.7 below.

Second, a round wood supply function:

$$S_{ik} = S_{ik}^* \gamma \left(\frac{P_{ik}}{P_{ik-1}} \right)^{\delta_{pk}} \quad (1.3)$$

where δ_{pk} is the price elasticity of supply for product k and S_{ik}^* is the supply computed based on the previous year’s price.

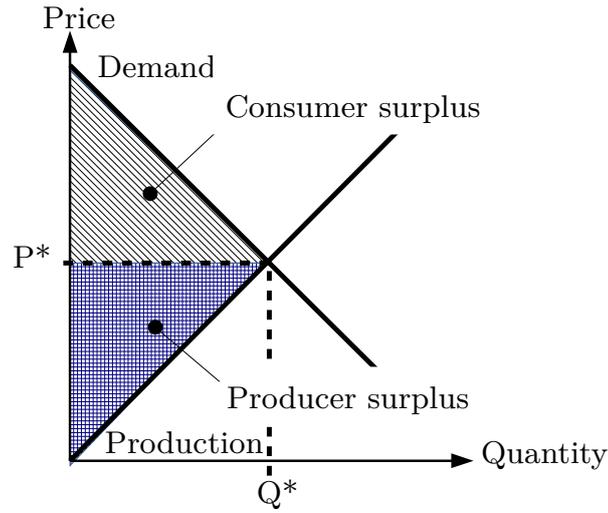


Figure 1.8.: Consumer and producer surplus

Third, production is the outcome of an input output matrix where secondary products n are manufactured from primary products k . 1.7 illustrates links between primary and secondary products. The production of a volume Y_{in} of secondary product requires an amount $a_{ikn}Y_{in}$ of primary product. Production is also subject to a manufacturing cost:

$$m_{in} = m_{in}^* \left(\frac{Y_{in}}{Y_{in-1}} \right)^{\lambda_{yn}} \quad (1.4)$$

where m^* is the current manufacturing cost at the previous year's output and λ_{yn} is the elasticity of manufacturing cost with respect to output.

Fourth, trade of product k from country i to country j is subject to transport costs:

$$t_{ijk} = f_{ijk} + \tau_{jk}(f_{ijk} + P_{k-1}) \quad (1.5)$$

where f_{ijk} is the freight cost τ_{jk} the import tariff in country j and P_{k-1} the world export price in the previous year. To avoid trade flows from changing drastically from one year to the next, trade is constrained with a lower and upper bound for each country.

Finally, product flows created by these four market agents are constrained by a material balance:

$$S_{ik} + Y_{ik} + \sum_j T_{jik} = D_{ik} + \sum_n a_{ikn}Y_{in} + \sum_j T_{ijk} \quad \forall_{i,k} \quad (1.6)$$

For a given product k in a country i , domestic supply, production and import from all countries is equal to domestic demand, demand for input in manufacturing secondary products and export to all countries.

1.3.3.2. Dynamic market shifts

In the dynamic phase, supply, demand and manufacturing costs are shifted from their value in the previous period to their value in the current period. Demand changes in function of a GDP growth rate r_g :

$$D^* = D_{-1}(1 + \beta_{gk}r_g) \quad (1.7)$$

where β_{gk} is the GDP elasticity of demand for product k .

Supply changes in function of a growth rate of forest stock r_f :

$$S^* = S_{-1}(1 + \delta_{fk}r_f) \quad (1.8)$$

where δ_{fk} is the supply elasticity with respect to forest stock for product k . Supply S^* will then be used in equation 1.3. Only primary products have a supply function: fuelwood and industrial roundwood (as illustrated Figure 1.7). Additionally, the supply of waste paper is shifted by the GDP growth rate:

$$S^* = S_{-1}(1 + \delta_{gk}r_g) \quad (1.9)$$

where δ_{gk} is the supply elasticity of waste paper with respect to GDP.

Manufacturing costs are shifted by a simple annual rate of change r_m :

$$m^* = m_{-1}(1 + r_m) \quad (1.10)$$

GFPM calculates a year over year change, then projections of demand and supply are adjusted by the static market equilibrium. A succession of dynamic and static phases constitutes a dynamic recursive partial equilibrium model. We are now focusing specifically on the demand side represented by demand elasticities β_{gk} and β_{pk} . Estimation issues are detailed in the next section.

1.3.4. Econometric modelling of forest products demand

In a review of 36 published articles, Toppinen and Kuuluvainen (2010) divide econometric analysis of the forest sector into five branches:

“1) modelling forest products demand and supply, 2) analysing prices and testing of market integration, 3) forecasting market demand and prices, 4) studying factors affecting industry location and 5) technical development and factor demand.”

Demand models are included in all branches of forest sector analysis. The section below deals with point 3 “forecasting market demand” and point 5 “factor demand” because the secondary products of interest are a factor of production for the final processing industries.

1.3.4.1. Theoretical derived demand model

Secondary forest products (Figure 1.7) are consumed by secondary processing industries in the construction, furniture or publishing sector. Those intermediate products are not purchased by final consumers directly but they are input factors in the production of consumer goods. Accordingly, demand for an input factor can be derived from a firm production model à la Cobb-Douglas. Simangunsong and Buongiorno (2001) for example consider the following production function where a quantity of wood y and a quantity of labour and other goods z are used as input into the production of g units of output:

$$g = ay^bz^c \quad (1.11)$$

The company minimises production costs with p_y and p_z the prices of y and z :

$$\min(y p_y + z p_z)$$

Replacing z by its value in 1.11 the cost minimisation problem becomes:

$$\frac{\partial (y p_y + g^{\frac{1}{c}} a^{-\frac{1}{c}} y^{-\frac{b}{c}} p_z)}{\partial y} = 0$$

Which leads to:

$$y = a^{-\frac{1}{b+c}} \left(\frac{c}{b}\right)^{-\frac{c}{b+c}} g^{\frac{1}{b+c}} \left(\frac{p_y}{p_z}\right)^{-\frac{c}{b+c}}$$

Considering that $\beta_0 = a^{-\frac{1}{b+c}} \left(\frac{c}{b}\right)^{-\frac{c}{b+c}}$, $\beta_1 = \frac{1}{b+c}$ and $\beta_2 = -\frac{c}{b+c}$, we obtain:

$$y = \beta_0 g^{\beta_1} \left(\frac{p_y}{p_z}\right)^{\beta_2} \quad (1.12)$$

The price of other goods p_z can be considered to be the price deflator, then the real price of the forest products is $p = \frac{p_y}{p_z}$. The output g is assumed to be correlated with the general economic output and is proxied by the GDP. Finally, the demand model frequently used for estimation purposes is expressed in logarithm:

$$\ln y = \beta_0 + \beta_1 \ln g + \beta_2 \ln p \quad (1.13)$$

This demand model considers one product in one country in one period. In the literature of interest, it is typically estimated on panel data for multiple products in multiple countries in multiple time periods. The benefit of panel data is that they enable greater variation across countries and should therefore improve the estimation of revenue and price elasticities of demand.

1.3.4.2. Relevance of considering a demand function isolated from the rest of the market

When econometric analysis of demand equation 1.13 is performed in isolation from the supply side, it is assumed that consumer behaviour is influenced by the international price of goods but consumption behaviour does not influence international prices in return, in other words the supply is perfectly elastic. Most of the literature on forest products demand follow this hypothesis and estimates a demand function isolated from the supply side of the market. Several authors consider that it would be better to estimate demand and supply equations simultaneously (Buongiorno, 1978; Kangas and Baudin, 2003) but do not use simultaneous equations because of a lack of independent data on supply, demand and prices.

Early econometric estimations of demand models included the influence of other products using cross price elasticities of demand. Houthakker (1965) developed panel based estimation methods for general macroeconomic demand model which inspired Buongiorno (1978) to apply them to forest products. The original demand model takes the following functional form:

$$C_{ijt} = \alpha_j + \beta_{1j} Y_{it} + \beta_{2j} P_{ijt} + \beta_{3j} P'_{ijt} + \epsilon_{ijt} \quad (1.14)$$

where C_{ijt} represents the consumption of product j in country i at time t , Y_{it} represents national revenue, P_{ijt} the price of product j and P'_{ijt} the price of substitute

products. All variables are expressed in logarithm and therefore the coefficients β_1 , β_2 and β_3 represent the revenue, own price and cross price elasticity of demand. In chapter 3, demand functions are estimated for intermediate forest products, those are products that enter into the production of final products. As in most of the literature on forest products demand functions, I make the simplifying assumption that the demand is not affected by the price of substitute products. This leaves the simple demand model frequently used to estimate forest products demand elasticities:

$$C_{ijt} = \alpha_j + \beta_{1j}Y_{it} + \beta_{2j}P_{ijt} + \epsilon_{ijt} \quad (1.15)$$

In some studies (Buongiorno, 1978; Hurmekoski and Hetemäki, 2013), consumption and GDP are expressed in kilogram per capita, and in constant US dollars per capita, while in other studies (Simangunsong and Buongiorno, 2001; Chas-Amil and Buongiorno, 2000), they are expressed directly in kilogram and in constant US dollars.

1.3.4.3. Spurious regression issues

The need for demand forecasts under various policy scenarios, and the regular availability of forest products market data, has pushed economists to improve demand models. Econometric estimates were published as early as the 1960ies, based on time series and cross section analysis in various countries. Buongiorno (1979) gave an overview of studies based on times series and cross sectional data and introduces the first panel data analysis of forest products demand. A number of other demand studies follow in these steps, using various versions of least squares estimators. For example Chas-Amil and Buongiorno (2000) estimate demand elasticities for paper products in the EU. Simangunsong and Buongiorno (2001) compare elasticities from 11 different other panel-based studies and re-estimates static and dynamic demand models using various estimation methods. In to their comparison, Least Square with Dummy variables is the most suitable estimator. Panel data analysis continue to be used, for example in Europe, Kangas and Baudin (2003) estimate forest products demand elasticities. Michinaka and Tachibana (2010) grouped countries by clusters to estimate different elasticities for different groups of countries. Issues with existing models push practitioners to update the estimation methodology regularly.

In a time series setting, Helles *et al.* (1999) introduce forest economists to issues related to unit root and cointegration tests. Many forest products times series turn out to be non-stationary. One way to estimate models with series that have a unit root is to differentiate variables. Differentiated variables provide information about the sign of a relationship, but they lose important information about the size of the effect. In the case of demand functions, differentiated variables doesn't allow us to estimate demand elasticities. Another way to extract information from series that have a unit root, is to test whether variables are cointegrated. Because a linear

combination of two or more non-stationary variables may be stationary. If variables are shown to be cointegrated, then coefficients from a long term relationship can be estimated directly in level. Cointegration tests in a time series context, are only suitable for time series which provide sufficient data point. Such tests do not have enough power on yearly data with a rather small number of years, commonly used with macroeconomic demand models. To increase power, panel version of these unit root and cointegration tests have been developed.

Almost none of the previously mentioned forest products panel studies test for the presence of unit root in the underlying time series of the panel. When non stationarity issues are mentioned (Hurmekoski *et al.*, 2015a), they are not considered a concern as long as the time dimension of a panel is short. Non-stationarity and cointegration issues have been the subject of intensive research with time series data (Abildtrup and Helles, 1998) but they have not yet been treated in a panel context. Chapter 3 attempts to fill that research gap by investigating non-stationarity issues and estimating elasticities in cointegrated panels. Chapter 4 describes ad-hoc demand models that introduce additional explanatory variables useful to specify structural changes ongoing in paper products demand.

2. Potential impact of a transatlantic trade and investment partnership on the global forest sector

2.1. Introduction

The United States (US) and European Union (EU) combined account for over 45% of the world GDP in nominal value and 38% in terms of purchasing power parity (World Bank, 2013). Foreign direct investment is intense between the two regions and more than a third of the trade consists of intra-company trade, between subsidiaries of companies established both in the EU and in the US (EC-Trade, 2013). Within the forest sector, the European Union and the United States account for around 40% of the world production of industrial roundwood, sawnwood and paper and paperboard, and for 30% of the world production of panels FAO (2012).

In 2010 the United States exported \$3.5 billion worth of forest products to the European Union, or 15% of its exports to all countries. Meanwhile, the European Union exported \$2.1 billion worth of forest products to the United States, or 6% of its total exports. However, Canada and China are the United States first trade partners for import and export of forest products in value (Table 2.1). China is the main destination of EU exports, and the United States is the EU main source of forest product imports (Table 2.1). Thus, while the relationship between the United States and the EU is substantial, it cannot be considered independently of the rest of the world. In investigating the potential impact on the forest sector of a trade agreement between the United States and the European Union, which is the subject of this study, it is important to place it in a global context.

Agreements to remove trade barriers aim at reducing dead-weight costs and at increasing net social gains from international trade. The World Trade Organisation (WTO) was established with the mandate to lower trade barriers among its 159 member countries through rounds of trade negotiations. The WTO's principle of "Most-favoured nation" (WTO, 2013) states that preferred treatment of one country "must be extended to all other members of the WTO". However exceptions to this principle are frequent due to the complexity of multilateral negotiation. There are hundreds of regional "free trade agreement", sometimes called "preferential trade agreements" (Bhagwati and Panagariya, 1996) as a reminder that third countries are excluded from the free trade gains.

The project of trade agreement between the US and the EU, also known as the Transatlantic Free trade Area (TAFTA Hamilton and Schwartz, 2012) or the Transatlantic Trade and Investment Partnership (TTIP Felbermayr, 2013) began with the 1995 Madrid Agreement on a Transatlantic Agenda, followed by various resolutions and negotiations by and between the US and the EU (Transatlantic Policy Network, 2007). In a recent report, the EU-US “high level working group on jobs and growth” (HLWG, 2013) analyses a range of options far beyond simple tariff removal, including: elimination of non-tariff barriers to trade in goods, services and investment, enhanced compatibility of regulations and standards and improved cooperation to achieve shared economic goals.

Table 2.1.: Value of forest products trade between the European Union and the United States, and other major countries in 2010

	1000 million \$US	Share		1000 million \$US	Share
US exports to:			US imports from:		
China	4.8	20%	Canada	12.6	62%
Canada	4.2	17%	EU	2.2	11%
EU	3.5	15%	China	1.3	7%
Mexico	3.2	13%	Brazil	1.2	6%
Japan	1.6	7%	Japan	0.4	2%
EU exports to:			EU imports from:		
China	4.1	12%	United States	3.5	16%
United States	2.1	6%	Brazil	3.3	15%
Switzerland	2.1	6%	Russian Fed.	2	9%
Turkey	2	6%	Norway	1.7	8%
Russian Fed.	1.7	5%	Switzerland	1.7	8%

Source: FAOSTAT, forestry trade flows, aggregated trade values in 2010 of roundwood, sawnwood, chips and particles, wood based panels, wood pulp, recovered paper, paper and paperboard.

Share of total EU or US exports.

Studies of how such deep agreements between the EU and US would influence the economies of the two regions and of the rest of the world vary greatly in terms of geographic coverage and quantitative estimates of impacts on economic growth, employment and trade. For example, the OECD report on “the benefits of liberalising product markets and reducing barriers to international trade and investment” (OECD, 2005) suggests that the annual growth rate of gross domestic product (GDP) per capita would increase by between 1% and 3% for the US and between 2 to 3.5% for the EU. Meanwhile, the Bertelsmann Foundation report (Felbermayr *et al.*, 2013a) estimates that a comprehensive agreement including removal of non-tariff trade barriers would, over one decade, raise the US GDP by up to 13% and the EU GDP by 5%. And, the Centre for Economic Policy Research (Francois *et al.*, 2013) predicts that a free trade agreement would accelerate GDP growth by between 0.01% and 0.39% for the US and between 0.02% and 0.48% for the EU by 2027.

All studies foresee a small impact of removing trade barriers alone, and a larger

impact of eliminating non-tariff barriers. Some disagree on the potential impact on third countries. While the OECD (2005) suggests that reducing barriers to trade between the EU and US will have mostly positive spill over effects on third party countries such as Canada, Mexico, Turkey and Japan, Felbermayr *et al.* (2013a) estimate that third party countries will lose market share in the US and the EU due to the increased trade between the two regions, and that this will have a negative effect on their economies. Additionally Felbermayr *et al.* (2013a) foresee a decrease in trade within EU countries, for example a 23% decrease in trade between France and Germany.

Most national and international studies on the macroeconomic impact of transatlantic trade agreements are based on general equilibrium approaches, such as the Global Trade Analysis Project (GTAP) model (Berden *et al.*, 2009; Francois *et al.*, 2013; OECD, 2005). Felbermayr *et al.* (2013a) combine the GTAP data base with trade gravity models (Egger and Pfaffermayr, 2011) into a general equilibrium model to project macroeconomic impacts of the TTIP in the US, the EU, and third countries.

The objective of this study was to use these macro general equilibrium results to predict their impact on the forest sector. The next section of the paper describes the theory, methods, and data used to this effect. This is followed by the results for the main countries and regions, by product group, consumption, production and prices, value added in industries, and welfare of producers and consumers. The conclusion summarizes the main results, some of their policy implications, and the limitations and potential improvement of the study.

2.2. Methods

2.2.1. Theory

The theoretical framework used for the study assumed competitive world markets for the demand, supply, and trade of forest products. The situation with and without a TTIP is sketched in Figure 2.1 for one single product, wood. Without the TTIP, the world demand, D_w , is the sum of the US and EU demand, D_u and D_e , and of the rest of the world demand. The world supply, S_w , is the sum of the US and EU supply, S_u and S_e , and of the rest of the world supply. The price P equilibrates world demand and supply (transport and other costs are ignored in the diagram as they do not affect the argument). At price P , the US is a net exporter by the amount X , and the EU is a net importer by the amount I . X and I need not be equal due to trade of the US and the EU with the rest of the world. The TTIP stimulates the economies of the US and the EU and also affects the rest of the world. The net result is a shift of world demand from D_w to D_w' , due in part to the demand shifts in the US from D_u to D_u' and in the EU from D_e to D_e' . The new global equilibrium is at price P' .

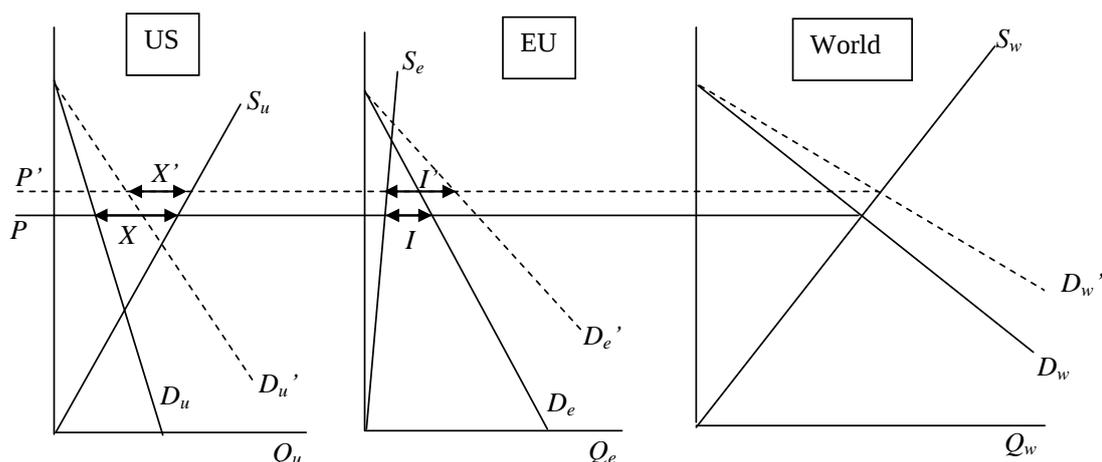


Figure 2.1.: World demand, supply, and trade of wood, with and without a Transatlantic Free Trade Agreement.

At that price, the US is still a net exporter, but by a lesser amount, $X' < X$, and the EU is still a net importer, but by a greater amount, $I' > I$. The diagram illustrates the possibility of a decrease of net trade (exports minus imports) due to the TTIP, in both the US and the EU, in the presence of the rest of the world. Ignoring the rest of the world would instead force the US net trade change to be the opposite of the EU net trade change, in a zero-sum game.

The total impact of a TTIP on the world forest economy was summarized by estimating the consumers and producers surplus, or welfare change (Varian, 1992, pp 222-224), with and without an agreement. Figure 2.2 symbolizes the procedure for the world economy and one product, wood. Point B is the equilibrium without TTIP, at quantity Q and price P. Point B' is the equilibrium after the positive shift of global demand induced by the TTIP. The area of the triangle ABP measures the consumers' surplus without the TTIP, the difference between the total value of wood consumption, measured by the area under the demand curve from O to Q, and the expenditure on wood, $P \times Q$. The area of the triangle OPB is the profit, or producers' surplus without the TTIP. The effect of the demand shift induced by the TTIP is to increase the price to P', and the consumption and production to Q'. Since the supply curve is unchanged, the price increase and the quantity increase raise the producers' surplus by the amount measured by the area PBB'P'. However, the consumers' surplus, measured by the area of the triangle P'B'A may be larger or smaller than without the TTIP depending on the elasticity of demand.

2.2.2. Global Forest Products Model

The Global Forest Products Model (GFPM) was used to quantify the effects sketched in Figures 2.1 and 2.2. The model was described originally in Buongiorno *et al.* (2003) and updated in Buongiorno and Zhu (2013a; 2013b). The GFPM represents

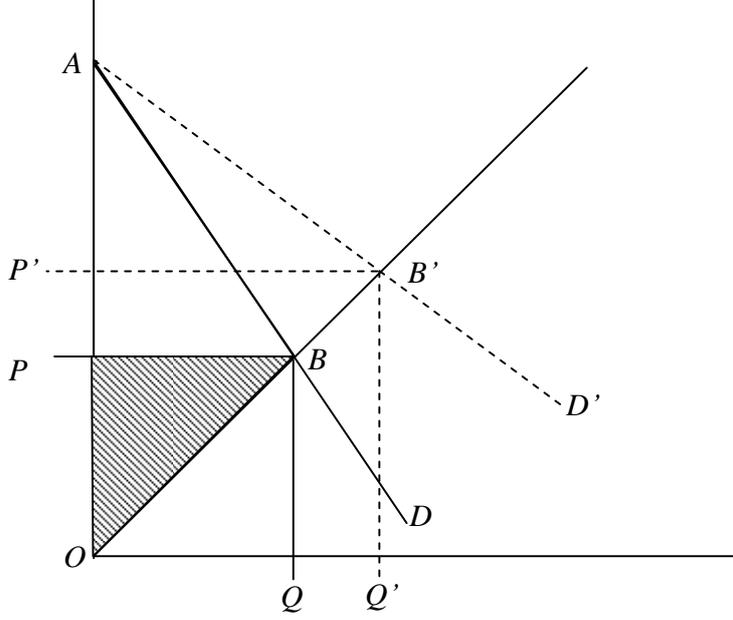


Figure 2.2.: Consumer and producer surplus without a Transatlantic Free Trade Agreement (area OAB) and with TTIP (area OAB').

the dynamic evolution of demand, supply, and trade of fourteen commodity groups in 180 countries linked by trade. The model computes the global market equilibrium for all products in any given year and simulates the evolution of this equilibrium over time to project the future state of the sector. Following Samuelson (1952), the equilibrium in a given year is obtained by maximizing the sum of the consumers and producers surplus for all products and countries:

$$\max \left(\sum_{i,k} \int_0^{D_{i,k}} P_{ik}(D_{ik}) dD_{ik} - \sum_{i,k} \int_0^{S_{i,k}} P_{ik}(S_{ik}) dS_{ik} - \sum_{i,k} \int_0^{Y_{i,k}} m_{ik}(Y_{ik}) dY_{ik} - \sum_{i,j,k} c_{ijk} T_{ijk} \right) \quad (2.1)$$

Where i and j refer to countries, k to products, P is the price, D is the end-product demand, S the raw material supply, Y the manufactured quantity at marginal cost m , and T is the quantity transported at cost c , including tariff and taxes. Thus, the first integral measures the value the end products to consumers, the second and the third the cost of production, and the last part is the transport cost. The optimization is subject to the following demand-supply equilibrium constraint for

each country and product:

$$\sum_j T_{jik} + S_{ik} + Y_{ik} = D_{ik} + \sum_n a_{ikn} Y_{in} + \sum_j T_{ijk} \quad \forall_{i,k} \quad (2.2)$$

where a_{ikn} is the input of product k per unit of product n . The left part of the equation is the sum of the imports, domestic supply, and manufactured quantity of a product in a country, while the right part is the sum of the domestic demand for the end products, the demand for input in manufacturing other products, and the exports to other countries. The primal solution of this constrained optimization gives the quantities consumed, produced, and traded, while the dual solution gives the equilibrium price for each product and country.

For this study the model was re-calibrated for the base year 2010, following the procedure described in Buongiorno and Zhu (2013a), using the three year average of 2009 to 2011. The data on production, imports, exports, and prices were obtained from the FAOSTAT database FAO (2012). The elasticities of demand and supply were the same as those estimated in the USDA Forest Service Global Outlook Study (Buongiorno *et al.*, 2012). After following this calibration procedure, the GFPM solution for 2010 closely replicated the observations for the same year.

The dynamic part of the GFPM describes the shifts of demand and supply over time due to economic and demographic growth, and changes in forest area and forest stock. Here, the projected changes of gross domestic product (GDP) and GDP per capita were obtained from USDA-ERS (2012). The parameters of the equations predicting changes of forest area, forest stock, and forest supply (Turner *et al.*, 2006), were as in Buongiorno *et al.* (2012).

2.2.3. Effects of the TTIP

The GFPM model was used to project the evolution of the global forest sector from 2010 to 2030, with and without the TTIP. Since the tariffs on forest products in the US and the EU were small, the maintained hypothesis was that the direct effect of tariff elimination would be negligible. This is in accord with previous findings that the macroeconomic effects of only eliminating tariffs, in all sectors, are quite small Felbermayr *et al.* (2013a); Francois *et al.* (2013). Thus, the main effect on the forest sector would be indirect, through the impact of the GDP growth brought about by the TTIP on the demand for forest products in the EU, the United States, and other countries.

In the GFPM, the demand for forest products in a given year is represented by econometric equations of the form Buongiorno and Zhu (2013b):

$$D_{ik} = D_{ik}^* \left(\frac{P_{ik}}{P_{ik,-1}} \right)^{\delta_{ik}} \quad (2.3)$$

Where D^* is the current consumption at last year's price, P_{-1} , and δ is the price elasticity of demand. D^* depends on last period's consumption, and the growth of GDP in the country:

$$D^* = D_{-1}(1 + \alpha_y g_y + \alpha_0) \quad (2.4)$$

Where g_y is the GDP annual growth rate, α_y is the elasticity with respect to GDP, and α_0 is an optional annual trend¹. With this structure, the effect of the TTIP was obtained by setting the GDP annual growth rate to what it would be with or without the agreement.

Table 2.2.: Assumed impact of the TTIP on annual percent growth rate of GDP in world regions and selected countries, derived from Felbermayr et al. (2013a) low and high impact scenarios.

	High impact (%)	Low impact (%)
AFRICA	-0.24	-0.15
NORTH/CENTRAL AMERICA	0.94	0.05
United States	1.26	0.07
SOUTH AMERICA	-0.24	-0.02
ASIA	-0.26	-0.04
OCEANIA	-0.7	-0.06
EUROPE	0.42	0.01
EU-28	0.62	0.03
Austria	0.27	0.01
Finland	0.61	0.04
France	0.26	0.02
Germany	0.46	0.02
Italy	0.48	0.03
Spain	0.64	0.03
Sweden	0.71	0.03
United Kingdom	0.93	0.04
WORLD	0.33	0

2.2.4. Macroeconomic scenarios

The magnitude and the range of the total impact of the TTIP on GDP were taken from Felbermayr *et al.* (2013a) who give estimates for the United States, the 27

¹In the numerical solution, each demand curve equation [3] is approximated by its tangent, $P = a + bD$, at the point $(D^*, P - 1)$, with $b = P_{-1}/\delta D^*$ and $a = P_{-1}(1 - 1/\delta)$. Thus, the effect of GDP growth as in [4], which sets D^* , is to change the slope, b , inducing a rotation of the demand curve as in Figure 2.2.

countries of the European Union, and 98 countries of the rest of the world. With their macro general equilibrium model, Felbermayr *et al.* (2013a) consider two scenarios. A “low impact” scenario calculates only the direct effect of reducing trade costs by eliminating existing tariffs in all sectors. The “high impact” scenario adds the removal of non-tariff barriers and projects the impact of the increase in trade activity on investments and economic growth.

For the purpose of the present study projections of the cumulative change in GDP with the low or high scenario were converted into annual growth rates over a decade, the time needed for almost full impact (Felbermayr, 2013). It was further assumed that the effect of the TTIP on GDP would begin in 2015 and end in 2025, but the simulations continued until 2030 to absorb any residual dynamic effect on the forest sector. Table 2.2 shows the effects of the TTIP on the growth rate of GDP implemented in the GFPM, according to Felbermayr *et al.* (2013a)². Countries of the European Union experience an average increase in their annual growth rate of GDP averaging between 0.03 and 0.62 percent depending on the scenario, while for the United States it is approximately between 0.07 and 1.26 percent. In other regions, the TTIP depresses growth due to “losses in market share from intensified competition on the EU or US markets” (Felbermayr *et al.*, 2013a), in particular annual GDP growth is 0.04 to 0.26 percent lower in Asia, and 0.22 percent lower in Russia in both scenarios. In the high scenarios the annual growth of the world GDP is 0.33 percent higher (i.e. about 3.3 percent higher over a decade) with the TTIP than without it, while in the low scenario the TTIP has practically no impact at the global level, although it does have an effect on the US and the EU.

2.3. Results

2.3.1. Price effects

The effects of the TTIP on world prices, at constant US dollars of 2010, are summarized in Table 2.3. In this version of the GFPM all countries export to a world region and import from it. For each commodity, the world price is the unit value of total world exports. The Table 2.3 shows the predicted world price in 2030 with the base scenario, i.e. without a TTIP, and the percentage difference in price with the high-impact and low-impact scenario of Felbermayr *et al.* (2013a). Under the high-impact scenario, the demand shift of end products tended to increase slightly (less than 1%) the prices of roundwood and of the products that depend heavily on roundwood: sawnwood, wood-based panels, and wood pulp. The price of printing and writing paper and other paper and paperboard was barely lower with the TTIP under the high-impact scenario. This was due mostly to a decrease in the price

²For countries that are in the GFPM but not in Felbermayr *et al.* (2013a) it was assumed that the TFTA would have no effect on the growth rate of GDP per capita. Consequently, the world effect in Table 2.2 differs slightly from Felbermayr *et al.* (2013a).

Table 2.3.: World prices of forest products in 2030 and differences due to the TTIP, predicted with the GFPM model under the high impact scenario.

	Base	Difference with high impact scenario
	$\$/m^3$	
Industrial roundwood	94.1	0.70%
Sawnwood	244.9	0.50%
Veneer & plywood	679.3	0.10%
Particleboard	362	0.20%
Fiberboard	581.9	0.10%
	$\$/t$	
Mechanical pulp	632.2	0.30%
Chemical Pulp	724.1	0.20%
Other fiber pulp	1357.7	-0.10%
Waste paper	199	-0.90%
Newsprint	648.3	0.10%
Printing & writing paper	967.3	-0.10%
Other Paper & paperboard	1090.3	-0.10%

Prices in constant \$US of 2010.

of waste paper, an important input in the manufacture of paper and paperboard, induced by the increased supply of waste paper due to higher consumption of paper and paperboard (see Table 2.8 below). Under the low-impact scenario of the TTIP there was hardly any difference in the world price of forest products in 2030, relative to the base scenario.

2.3.2. Effects on industrial roundwood

Under the TTIP high-impact scenario, the world consumption and production of industrial roundwood was nearly 8 million m³ higher in 2030 than with the base scenario (Table 2.4). This increase occurred largely in North America and Europe. Consumption was higher both in the United States and in the EU by about 3 million m³, but it was slightly lower in Russia. Production increased by 2.6 million m³ in the EU and less than 1 million m³ in the US. As a result, the trade balance of industrial roundwood deteriorated much more in the US than in the EU. This was compensated by an improvement of net trade in other countries, in Europe outside the EU (mainly Russia) and in Asia.

With the low-impact scenario, the world consumption and production of industrial roundwood were less than 1 million m³ lower in 2030 than without the TTIP. There was only a small increase of consumption in the EU and the US, while production decreased, leading to a decrease of net trade in both regions.

Table 2.4.: Differences in industrial roundwood consumption, production, and net trade in 2030 due to the TTIP, predicted with the GFPM model under the high and low impact scenarios.

	High impact (1000 m3)			Low impact(1000m3)		
	Consumption	Production	Net trade	Consumption	Production	Net trade
AFRICA	-258	219	477	-39	-58	-19
N/C AMERICA	4354	2101	-2253	67	-88	-155
United States	3152	703	-2449	66	-58	-124
SOUTH AMERICA	667	696	28	-68	-62	6
ASIA	57	1082	1025	-454	-316	139
OCEANIA	203	-137	-340	-11	6	17
EUROPE	2720	3783	1063	-112	-100	12
EU-28	3027	2613	-414	10	-69	-79
Austria	279	72	-207	15	-2	-17
Finland	372	274	-98	33	-9	-42
France	565	239	-327	-20	-8	12
Germany	480	480	0	-4	-4	0
Italy	220	-1	-221	7	-1	-8
Spain	121	103	-18	-4	1	5
Sweden	337	461	124	11	-16	-26
United Kingdom	70	70	1	-5	-4	1
WORLD	7743	7743	0	-618	-618	0

2.3.3. Effects on sawnwood

According to GFPM projections for the high-impact scenario, the TTIP agreement raised the world sawnwood consumption and production in 2030 by 1.4 million m³ (Table 2.5). However, it lowered consumption in countries outside of Europe and North America. In the US consumption was nearly 2 million m³ (3%) higher. This additional consumption was not accompanied by a higher production but rather by a degradation of the US net trade. In the EU sawnwood consumption was 0.9 million m³ (1%) higher with the high-impact TTIP, an amount more than compensated by the EU additional production. In other regions, due to the lower consumption in Asia, South America, and Africa, their trade balance improved.

The low-impact scenario had a negligible effect on world production, consumption, and trade of sawnwood. While the TTIP increased consumption slightly in the EU and the US, it decreased it more in other regions, especially in Asia, leading to a slightly lower world consumption and production in 2030.

2.3.4. Effects on wood-based Panels

Three product groups distinguished in the GFMP model are aggregated here under wood-based panels: Veneer and plywood, fiberboard, and particleboard. With the high-impact scenario of the TTIP the world consumption of wood-based panels was 1.9 million m³ higher in 2030 than with the base scenario, but it was 0.7 million m³ lower in Asia, and also lower in South America, Oceania, and Africa

Table 2.5.: Differences in sawnwood consumption, production, and net trade in 2030 due to the TTIP, predicted with the GFPM model under the high and low impact scenarios.

	High impact (1000 m3)			Low impact(1000m3)		
	Consumption	Production	Net trade	Consumption	Production	Net trade
AFRICA	-100	29	129	-57	-8	50
N/C AMERICA	1478	598	-881	64	0	-64
United States	1954	-40	-1994	109	-6	-115
SOUTH AMERICA	-212	-174	38	6	14	8
ASIA	-411	88	499	-139	-138	1
OCEANIA	-107	-22	85	-10	-3	8
EUROPE	771	902	131	-19	-20	-2
EU-28	885	977	91	46	-27	-74
Austria	29	66	37	2	0	-2
Finland	52	139	87	3	16	13
France	57	199	142	4	-5	-9
Germany	185	187	3	8	10	2
Italy	67	57	-10	4	-1	-5
Spain	42	31	-12	2	3	2
Sweden	80	85	6	3	-2	-5
United Kingdom	165	-73	-237	7	-10	-17
WORLD	1420	1420	1	-155	-154	1

Note: World net trade may not add up to 0 due to round-off errors.

(Table 2.6). Consumption was 6% higher in the US and 2% higher in the EU. Increased consumption was supplied by an increase in production in the EU, leaving net trade practically unchanged. Meanwhile the US witnessed a nearly equal increase in production and net imports. Asia lowered more its consumption of wood-based panels than production with an attendant improvement in the trade balance.

With the low-impact scenario the largest effect was lower consumption and production in countries outside the TTIP by 2030, mostly in Asia, while there was a slight increase in both production and consumption in the EU and US.

2.3.5. Effects on wood pulp

The GFPM model simulates the transformation of industrial roundwood into sawnwood, wood-based panels, and into intermediate products for the paper industry: mechanical pulp and chemical pulp. These intermediate products, together with other fibre pulp and waste paper are in turn transformed in end products: Newsprint, printing and writing paper and other paper.

With the TTIP high-impact scenario, consumption of wood pulp, the sum of mechanical and chemical pulp, was 5% higher in the US and 1% higher in the EU (Table 2.7). Production in both regions increased less than consumption, thus worsening their trade balance. There was little change in wood pulp consumption in other regions, leading to a total global increase in annual consumption of 1.7 million m3

Table 2.6.: Differences in wood-based panels consumption, production, and net trade in 2030 due to the TTIP, predicted with the GFPM model under the high and low impact scenarios.

	High impact (1000 m3)			Low impact(1000m3)		
	Consumption	Production	Net trade	Consumption	Production	Net trade
AFRICA	-50	-33	17	-38	-12	26
N/C AMERICA	1751	1103	-649	85	66	-18
United States	2181	1055	-1126	121	58	-63
SOUTH AMERICA	-156	-90	66	-2	-20	-18
ASIA	-654	-211	443	-210	-189	21
OCEANIA	-87	-11	77	-9	-20	-11
EUROPE	1094	1139	46	-46	-44	2
EU-28	1243	1220	-23	66	43	-23
Austria	16	129	113	0	17	17
Finland	17	-15	-32	1	-5	-6
France	60	124	64	5	-8	-12
Germany	238	246	8	11	2	-9
Italy	117	112	-5	6	8	2
Spain	55	-19	-74	3	-10	-13
Sweden	53	27	-26	2	4	2
United Kingdom	232	170	-61	9	9	0
WORLD	1898	1897	0	-221	-220	1

Note: World net trade may not add up to 0 due to round-off errors.

by 2030. Production increased the most in the United States and South America where net exports increased substantially.

With the TTIP low-impact scenario there was practically no change in wood pulp consumption, production, and trade in the EU and the US, and only a small decrease of world production and consumption by 2030.

2.3.6. Effects on paper and paperboard

Under the high-impact scenario, the TTIP raised the world annual consumption of paper and paperboard by nearly 4 million metric tons in 2030. There were substantial increases of consumption in the US (6%) and in the EU (2%) by 2030, relative to the base scenario (Table 2.8). In both the EU and the US this increased consumption was supplied by more production and less net exports. The consumption of paper and paperboard in Asia was 1.4 million tons lower, due mostly to decreases in Japan and China. However, China's production increased sufficiently to improve markedly Asia's net trade.

With the low-impact scenario of the TTIP, there was little change in the situation of the paper and paperboard sub sector in 2030. While consumption and production increased slightly in the US and the EU, there were larger declines in other countries, in Asia in particular.

Table 2.7.: Differences in wood pulp consumption, production, and net trade in 2030 due to the TTIP, predicted with the GFPM model under the high and low impact scenarios.

	High impact (1000 m3)			Low impact(1000m3)		
	Consumption	Production	Net trade	Consumption	Production	Net trade
AFRICA	-69	-51	18	-13	-6	7
N/C AMERICA	1599	1108	-491	51	-1	-52
United States	1840	1114	-726	72	8	-64
SOUTH AMERICA	-100	322	422	3	-16	-19
ASIA	-146	91	237	-102	-61	41
OCEANIA	-19	55	74	-4	-4	1
EUROPE	440	180	-260	-43	-20	23
EU-28	474	192	-282	19	-7	-26
Austria	14	22	8	1	-4	-5
Finland	43	42	-1	3	3	0
France	61	59	-3	5	-1	-6
Germany	102	70	-32	5	-9	-13
Italy	84	8	-76	2	1	-1
Spain	53	51	-2	3	2	-1
Sweden	47	46	0	2	3	1
United Kingdom	58	9	-48	2	0	-2
WORLD	1704	1704	1	-109	-108	1

Note: World net trade may not add up to 0 due to round-off errors.

2.3.7. Effects on value added

For this study, the value added in the forest sector of a country was defined as the total value of the end products (sawnwood, wood-based panels, paper and paperboard) manufactured in the country, minus the cost of the wood and fiber consumed in making them.

According to the high-impact scenario, the TTIP increased the value added in the US forest sector by \$3.5 billion a year in 2030, or 3.7%, and in the EU by \$1.7 billion, or 1.2% (Table 2.9). Most third party countries experienced a decrease in value added, in particular in Asia, where Japan's value added was \$800 million lower, and in South America. Nevertheless, in total, the world value added increased by \$3.6 billion.

With the low-impact scenario, value added increased barely in the US and the EU. Overall, global value added was slightly lower than with the base scenario, mostly due to the deterioration in Asia, primarily in China and India.

2.3.8. Welfare effects

The second column of Table 2.10 shows the difference in consumers' surplus or welfare, between the high-impact scenario and the base scenario. For all end products considered by the model (fuelwood, sawnwood, panels, paper and paperboard), the TTIP raised the consumers' welfare in 2030 by about \$16 billion for the world. Most

Table 2.8.: Differences in paper and paperboard consumption, production, and net trade in 2030 due to the TTIP, predicted with the GFPM model under the high and low impact scenarios.

	High impact (1000 m3)			Low impact(1000m3)		
	Consumption	Production	Net trade	Consumption	Production	Net trade
AFRICA	-120	-126	-6	-66	-32	34
N/C AMERICA	3741	2744	-997	164	72	-92
United States	4349	3235	-1115	240	129	-112
SOUTH AMERICA	-234	-190	44	-16	3	19
ASIA	-1382	-151	1231	-498	-425	74
OCEANIA	-172	-32	140	-16	-8	8
EUROPE	1968	1555	-413	21	-21	-42
EU-28	2099	1628	-470	102	76	-25
Austria	30	42	12	1	2	1
Finland	41	64	23	3	5	2
France	124	174	50	10	13	3
Germany	454	466	12	21	22	1
Italy	236	226	-11	12	7	-5
Spain	197	198	0	10	10	0
Sweden	72	63	-9	3	3	0
United Kingdom	526	266	-260	20	10	-10
WORLD	3801	3800a	0	-411	-411	0

Note: World production may differ from consumption due to round-off errors.

of this gain was in the US (nearly \$14 billion) and in the EU (\$6.8 billion). Meanwhile, Asia lost \$1.7 billion in consumer surplus, due in large part to a decrease in Japan.

The gain of the world producers of wood and fiber was much smaller than that of consumers, less than \$1 billion, spread through all countries but highest in the EU, Asia, and the US. The total welfare change, the sum of producers' and consumers' surplus was double for the US than for the EU. Within the EU Germany and the United Kingdom gained the most. Among third-party countries, those in Asia suffered the largest welfare losses.

With the low-impact scenario, there was practically no change in producers' surplus. All the welfare differences came from consumers' surplus (Table 2.10, last 4 columns). The world welfare was \$1.6 billion lower. Although there were some welfare gains in the US and the EU, decreases in Asia were larger, stemming in part from large declines in consumers surplus in China and India.

2.3.9. Sensitivity analysis

A sensitivity analysis was carried out to judge how much this measure of the total welfare impact of the TTIP varied with the choice of parameters. Focus was on the elasticity of demand with respect to GDP since the effect of the TTIP was traced through its impact on the GDP growth which in turn affected the demand for forest products. In addition to the projections discussed above, with an average elasticity

Table 2.9.: Differences in value added in 2030 due to the TFTA, predicted with the GFPM model under the high and low impact scenarios.

	High impact		Low impact	
	Million \$		Million \$	
AFRICA	-133	-2.7%	-31	-0.6%
N/C AMERICA	3058	2.5%	72	0.1%
United States	3460	3.7%	123	0.1%
SOUTH AMERICA	-118	-0.4%	-21	-0.1%
ASIA	-635	-0.2%	-563	-0.2%
OCEANIA	-33	-0.5%	-20	-0.3%
EUROPE	1505	0.9%	-51	0.0%
EU-28	1663	1.2%	29	0.0%
Austria	82	0.8%	1	0.0%
Finland	28	0.2%	2	0.0%
France	142	1.2%	-2	0.0%
Germany	537	1.3%	8	0.0%
Italy	205	2.1%	8	0.1%
Spain	175	2.1%	4	0.1%
Sweden	30	0.3%	1	0.0%
United Kingdom	288	3.5%	10	0.1%
WORLD	3643	0.5%	-614	-0.1%

Note: Value added in constant \$US of 2010.

of demand with GDP, the projections were repeated with “high” and “low” elasticity defined by the mean elasticity plus or minus one standard error, corresponding to a 70% confidence interval (Table 2.11).

The variability of the results was measured by the coefficient of variation, the standard deviation divided by the absolute value of the mean, over the projections with a high, low, or mean elasticity. The results, in the middle and last column of Table 2.10, show that the total welfare impact of the high TTIP impact scenario varied by approximately 11% for the United States and by 9% for the EU, depending on the elasticity of demand with GDP. For the world the variation was 9%, but it was two to three times larger for Asia and South America.

In the case of the low TTIP impact scenario, the coefficient of variation for the EU and the US was also near 10%. But it was larger for the world and for South America and for some individual countries, thus strengthening the inference that little or no change could be attributed to the low impact scenario.

Table 2.10.: Differences in consumer surplus, producer surplus, and total welfare in 2030 due to the TFTA, predicted with the GFPM model under the high and low impact scenarios.

	High TTIP impact (million \$)				LowTTIP impact (million \$)			
	Consumers	Producers	Total	CV	Consumers	Producers	Total	CV
AFRICA	454	82	536	18%	-309	-8	-317	7%
N/C AMERICA	11704	229	11933	10%	439	-3	436	9%
United States	13645	127	13772	11%	700	-1	699	10%
SOUTH AMERICA	-354	95	-259	30%	-24	-2	-25	37%
ASIA	-1721	209	-1513	21%	-1482	-19	-1501	14%
OCEANIA	-460	12	-447	14%	-56	0	-56	14%
EUROPE	6450	322	6772	9%	-115	-7	-122	27%
EU-28	6764	228	6993	9%	271	-1	270	9%
Austria	156	7	162	8%	4	0	4	33%
Finland	224	23	247	8%	12	0	11	4%
France	486	23	510	8%	27	0	27	5%
Germany	1384	38	1422	9%	48	0	48	9%
Italy	684	3	687	9%	30	0	30	10%
Spain	520	9	529	9%	22	0	22	9%
Sweden	342	39	381	9%	11	0	11	9%
United Kingdom	1333	6	1339	11%	45	0	45	10%
WORLD	16073	949	17021	9%	-1547	-39	-1585	15%

Note: CV is the coefficient of variation of the total welfare impact based on projections with the low, high and mean elasticity of demand with GDP in Table 11.

2.4. Summary and conclusion

The purpose of this paper was to simulate the impact of a Transatlantic Trade and Investment Partnership on the global consumption, production and trade of forest products. As tariffs on forest products in the US and the EU are already low, the main effects of an agreement would not be due to the elimination of tariffs on forest products, but rather to its impact on the growth of GDP in the US, the EU, and the rest of the world, which would affect the demand for forest products. Two estimates of a TTIP impact on GDP growth were used, based on Felbermayr *et al.* (2013a): a “low impact” scenario, where only trade tariffs (in all sectors) were eliminated, simulating a direct reduction of trade costs; and a “high impact” scenario, where both tariff and non-tariff trade barriers were eliminated, with a deeper integration of the two market areas, liberating resources for more GDP growth. The Global Forest Products Model, recalibrated for the 2010 base-year, was then used to simulate the potential impact of these changes of GDP growth on the forest sector from 2010 to 2030.

According to the results, under the low-impact scenario the TTIP would have no, or only small consequences for the forest sector. With more comprehensive trade liberalization (the high-impact scenario including non-tariff barriers that need to be negotiated under the treaty), a TTIP would still have only a small positive effect on the world prices of most products, but it would change forest products consumption, production, and trade. For all forest products, consumption would increase about

Table 2.11.: GFPM demand elasticity with GDP and price.

	GDP elasticity			Price elasticity	Annual trend
	Mean	High	Low		
Sawnwood	0.22	0.25	0.19	-0.1	-0.003
S.E.	0.03			0.02	0.001
Plywood & veneer	0.41	0.45	0.37	-0.29	-0.009
S.E.	0.04			0.02	0.002
Particleboard	0.54	0.61	0.47	-0.29	-0.006
S.E.	0.07			0.02	0.002
Fiberboard	0.35	0.41	0.29	-0.46	-0.002
S.E.	0.06			0.02	0.002
Newsprint	0.58	0.62	0.54	-0.25	-0.008
S.E.	0.04			0.02	0.001
Printing & Writing	0.45	0.48	0.42	-0.37	0.003
S.E.	0.03			0.02	0.001
Other paper & Paperboard	0.43	0.46	0.4	-0.23	-0.004
S.E.	0.03			0.02	0.001

Note: Columns High and Low are the mean value plus or minus one standard error (S.E.) used for the sensitivity analysis in Table 2.10.

twice as much, in percent, in the US as in the EU. Production would increase less than consumption, leading to a deterioration of the trade balance in both the EU and the US, compensated by increased exports of some third countries. Global welfare (consumers and producers' surplus) would increase by approximately \$17 billion, of which \$14 billion in the US, and half as much in the EU, with some decrease in third countries, especially in Asia.

However, according to the sensitivity analysis, the measures of the welfare impact for the US and the EU may vary by $\pm 10\%$ depending on the elasticity of demand with GDP, and by as much as $\pm 30\%$ for Asia. This uncertainty points to the need for further research. In particular, for the issue examined here, more accurate estimates of the elasticities of demand by product and country are needed, with particular attention to how they may vary between countries and over time (Hetemäki and Obersteiner, 2001; Michinaka and Tachibana, 2010). Another area of potential improvement is in the modelling of trade, to achieve a compromise between purely competitive trade and the assumption that products from different countries are always different commodities (Armington, 1969). As an alternative, Felbermayr *et al.* (2013b) combine gravity trade models with a general equilibrium model (GTAP, Hertel and Hertel, 1997). They project a small positive effect of the TTIP on exports of wood and paper products in the United States and Germany, and a negative effect on forestry exports from Germany, but a positive effect in the United States. Meanwhile, the present study projected negative impacts on the United States' net trade of all products, and little impact on Germany's.

From the point of view of policy, to reach the high impact results, non-tariff barriers

for the forestry sector must be negotiated. The non-tariff barriers are defined in Berden *et al.* (2009) as “all non-price and non-quantity restrictions on trade in goods, services and investment, at federal and state level. This includes border measures (customs procedures, etc.) as well as behind-the border measures flowing from domestic laws, regulations and practices”. Regulations cannot be changed as easily as tariffs and are the results of differences in culture, geography or language. In the agriculture negotiations and it would be similar for forestry, the different political philosophies stem in part from a difference between the « science based information » guiding the US negotiators and the « precautionary principles » followed by the EU Grueff and Tangermann (2013).

For the forestry sector, the OECD product market regulation indexes, which measure non-tariff trade barriers, are a mere 0.10 for US exports, and 0.08 for EU exports on a scale from 0 to 1 (Berden *et al.*, 2009). Nevertheless, negotiators will have to agree on how to consider forest biodiversity protection for instance and how to harmonize the Lacey act and the EU regulation governing illegal logging. Also, different, sometimes incompatible quality norms and forest products classifications exist in the two regions and may hinder trade. It is largely unknown how deep a TTIP would impact timber and forest products classifications, eco-certifications and labeling.

While these limitations and uncertainties must be kept in mind in evaluating the results, they remain useful as estimates of the magnitude of a potential TTIP on the forest sector, acknowledging the wide range of its macroeconomic consequences depending on the depth of the reforms. Furthermore, the results illustrate the importance of a global perspective in evaluating the TTIP and other potential regional trade agreements, and their consequences on specific sectors. In particular, while considering only the US and the EU would force zero-sum trade, the present results suggest instead that the trade balance of both the US and the EU would deteriorate and be compensated by exports from third countries. Such inferences can be made effectively with a partial equilibrium model of the forest sector with sufficient country and product detail such as the GFPM, conditional on macro-economic projections obtained from economy-wide general equilibrium models.

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3. Reassessing forest products demand functions in Europe using a panel co-integration approach

3.1. Introduction

Forest resources supply a large industrial sector with renewable material. Indeed, paper and wood-based industries represent around 1% of the labour force and 1% of the GDP¹ in Europe (Lebedys and Li, 2014) or 5% of the agricultural and manufacturing GDP. Under every forest-related discussion, a vital policy question remains present in all minds: will forest resources continue to match forest products demand in the future? This two sided question is the object of extensive studies on the supply side. In the following article, we instead propose to analyse the demand side. In spite of the continuous development of alternative materials (such as plastic chairs, metallic roof structures, electronic news media), consumption volumes of forest based products more than doubled in the European Union over the past 50 years.

Final products being too numerous and diverse to analyse at a macroeconomic level, it is customary in this literature to analyse the demand for intermediate forest products. Those products based on forest raw material have only undergone one first processing step. To put these products in context, let us consider three industries producing three final products. For example, a printing press uses paper as an input to produce books. A carpenter uses coniferous sawnwood to produce timber framed roof structures and a furniture shop uses wood panels in the production of office furniture. Because our focus is on material uses of wood the forest based materials analysed in the present article are paper products, sawnwood and wood panels as opposed to biomass demand for energy uses. Between 1960 and 2000, paper and paper board consumption has been increasing from 20 million to 80 million tons in EU member countries. Sawnwood consumption has been fluctuating around 80 million m^3 per year over the same period. While wood panel consumption increased from 10 to 50 million m^3 over those 50 years (Figure 3.1). Focusing on the most recent three decades, table 3.1 illustrates wide variation in consumption patterns. During the 1990ies, a general increase in consumption could be observed for all forest products

¹The figure would be higher if it included the furniture and construction sectors.

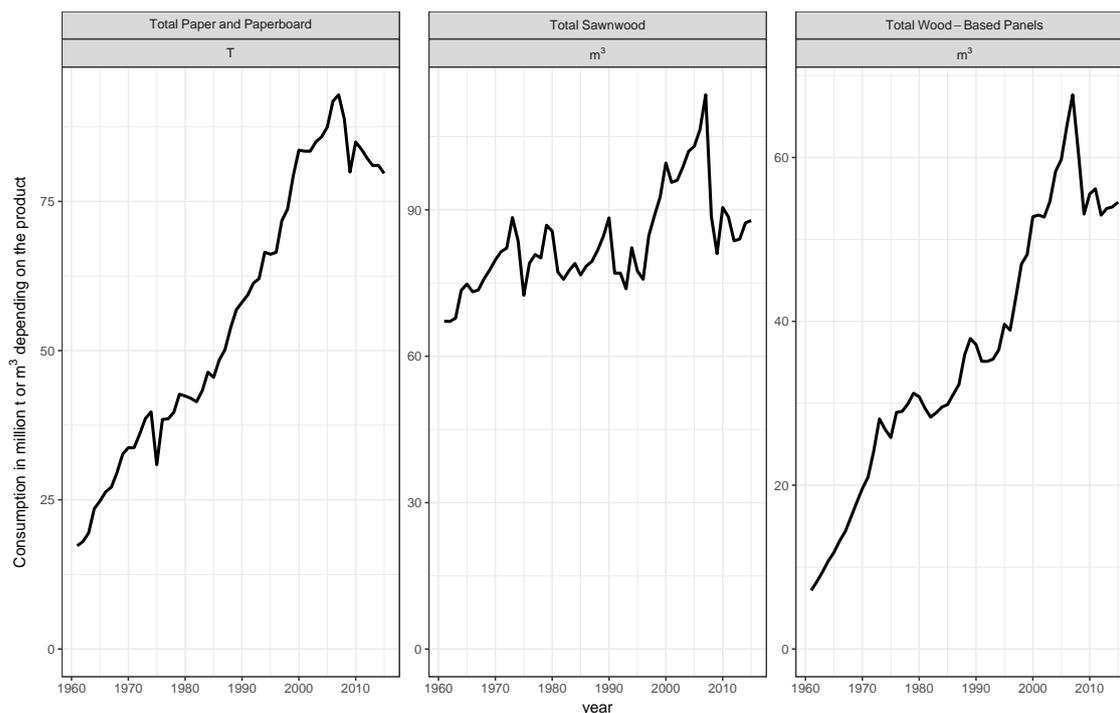


Figure 3.1.: Forest Products Consumption in the European Union

in EU member countries, with the exception of non coniferous sawnwood. Between 2000 and 2010 however, printing paper, newsprint and sawnwood consumption decreased notably. While other paper and paperboard (used mostly for packaging) and wood panel consumption continued to increase, though at a slower pace than the decade before. Changes in forest products consumption can be related partly to the business cycle and partly to structural changes in consumption practices. In other words, forest products markets expand or contract following the rest of the economy but also following their own dynamics. Accordingly economists are trying to model the mechanisms at play.

Two major drivers of change in the forest-based sector are environmental regulations and innovations. Compared with alternative materials such as concrete, steel, aluminium or plastic, wood requires less processing energy. Thus substituting wood for other materials leads to lower fossil fuel emissions. Additionally wood products can store CO₂ over decades in buildings. Both substitution and storage effects (Sathre and O'Connor, 2010) have led wood construction to be recommended in climate change mitigation policies that seek to lower emissions. Further information on the potential of forestry for climate change mitigation are provided in the chapter on Agriculture, Forestry and Other Land Use (AFOLU) of the IPCC 2014 report (Smith *et al.*, 2014). Similar environmental concerns in the packaging sector have led wood-based fibres to be preferred over plastic-based packaging. Additionally, under the emerging label of bioeconomy, the transformation of trees into bio-based

products such as textiles, plastic composites and pharmaceuticals is increasing (Hetemäki and Hurmekoski, 2016). In order to design adapted policies, decision makers need to be informed about the future intensity of forests uses.

For example several renewable energy policies use subsidies to encourage the substitution of fossil fuels with wood fuels (European Parliament, 2009). Such policies have led to an increase in wood energy use in Europe. On the solid wood side, sawmills can generally afford to pay higher prices for higher raw material qualities by virtue of generating more value-added than the fuel wood industry. However given enough time, policies encouraging bioenergy could lead to competition on raw material prices with fibre based and solid wood products. Recent research predicts strong tensions on forest products markets towards 2030 (Buongiorno *et al.*, 2011).

The policy debate on forest resources has been stimulated by a report called “EU-Wood”, commissioned by the European Commission (Mantau *et al.*, 2010, page 23). According to this report, increased demand for biomass would lead to wood shortages in the European Union towards 2020. However Hetemäki and Hurmekoski (2014) argued that shortages are not likely to happen because of three main points: firstly, structural changes lead to a reduction in biomass demand in some sub-sectors, secondly increased imports can compensate increased demand and thirdly, the forest sector responds to price signals. Analysing any of these three market interactions requires an up-to-date demand model.

The literature section below provides an overview of macroeconomic models used to estimate the determinants of wood consumption. These models are commonly based on two main explanatory variables: prices and GDP. As pointed below and by Toppinen and Kuuluvainen (2010), there is a lack of econometric analysis at the European level. In this paper, we thus try to fill this gap by reassessing the forest products demand models using new panel econometric tools. Do classical models - with a positive revenue elasticity of demand, close to one and a negative price elasticity of demand - provide a relevant description of demand in European countries?

We anticipate that an improved understanding of limitations and strengths of current models will support both private and public policy makers in their investment decisions. Some context might help to clarify the importance of demand models for decision makers. By private decision makers, we mean forest owners on the raw material supply side and the primary processing industry on the demand side: sawmill, pulp and paper and panel industries. Forest owners invest over long time horizons in the range of 40 years for pine trees to 100 years and beyond for oak trees. Likewise, the primary processing industry invests over a long period of time. Indeed, most companies use capital intensive machinery such as sawmill production lines, wood dryers, paper mill machinery, wood panel presses. In order to achieve economies of scale, these production processes are large and need several decades to generate enough return on investment. Thus private policy makers are in need of long term demand scenarios.

A description of the various public policies impacting the forest sector is beyond the scope of this article but we can give two examples of policy interactions. When public decision makers subsidise the installation of district and residential heating based on bio-fuels, the resulting increase in wood fuel demand provides positive benefits both in terms of lower fossil fuel emissions and in terms of additional revenue for forestry operations. In this case, the policy objectives of climate change mitigation and rural development are aligned. In other cases, policy objectives can be conflicting when for example subsidies provided to utility scale electricity production from wood biomass destabilize the relatively smaller forest sector. Utility scale demand for wood biomass matched with constrained supply can create price increases that are not sustainable for other industries such as sawmills, panel and paper industries in a given region. Whether biomass price developments threatens traditional forest industries is debatable. Simulations have shown that high fuel wood demand could lead to high raw material prices for solid wood and wood fibre towards 2030 (Buongiorno *et al.*, 2011). The purpose of this article is not to look at fuel demand, but at the demand for solid wood and wood fibre based products. Increased competition between sub-sectors could lead to severe price increases. Therefore, an improved knowledge of demand elasticities helps to elaborate scenarios of future demand and it also helps in describing which sub-sector will be affected most by policy changes.

From an econometric point of view, international forest products demand can be analysed using cross sectional data, time series data, as well as panel data. Panel data is the most interesting approach since it allows to capture effects in both the time and country dimensions. Besides, we focus on the long-run relationships between forest products consumption, national revenue and prices. As the available time dimension of a panel grows, non stationarity issues start to be visible and estimations based on non stationary panels could lead to spurious regression. However, this feature has been clearly neglected in previous literature about forest products demand models. Hence, this article uses recent non stationary panel techniques to derive robust elasticities. Section 3.2 presents an overview of the literature on panel data analysis of forest products demand. Section 3.3 outlines the model and the data set preparation. Panel unit root tests and cointegration tests are presented in the methodology section 3.4. Finally, tests and estimations results are discussed in section 3.5.

3.2. Literature

Several simulation models have been developed specifically for forest products based on Samuelson's theory (1952) of equilibrium between supply, demand and international trade. For instance, both the Global Forest Products Model (Buongiorno *et al.*, 2003) and the EFI-Global Trade Model (Kallio *et al.*, 2004) are routinely used to simulate demand and supply scenarios for North America and Europe (UNECE-FAO, 2006, 2011). From a historical perspective, Buongiorno (1996) presents co-

development in econometrics, linear programming and systems dynamics which lead to forest sector modelling. Demand functions are a crucial component of these models because they represent the interaction of the rest of the economy with the supply side, which is the forest sector. Long term demand elasticities being relatively stable, they tend not to be assessed very often. Yet, in a review of forest sector modelling approaches, Toppinen and Kuuluvainen (2010) warn that a lack of recent multi-country econometric analyses place forest sector simulation models on an unstable ground. Since calibration parameters have become out-dated, results from such global models are now questionable. Thus, revenue elasticities of demand are expected to be lower than in for example Simangunsong and Buongiorno (2001), Kangas and Baudin (2003). Inaccurate parameters, give rise to unreliable simulation results and subsequent flawed policy recommendation. It is therefore critical for forest sector models to be based on up-to date and robust demand elasticities, using the most suitable econometric techniques.

Over the past 50 years, aggregate consumption of forest products has been the subject of econometric analysis based on cross section, time series and panel data. One branch of the forest sector analysis literature focuses on demand models for forest products at the macroeconomic level. Various articles estimate a country's forest products consumption as a function of real Gross Domestic Product, real prices and possibly other variables. Several modelling efforts use pooled time series to analyse the impact of national revenue and prices on per capita consumption of paper products (Buongiorno, 1978) or sawnwood and wood panels (Buongiorno, 1979). Notably Chas-Amil and Buongiorno (2000) estimate demand functions for paper products on a panel of EU countries using pooled time series analysis and standard panel fixed effect models.

Most panel based studies make the hypothesis that demand elasticities are homogeneous in time and across countries. However, some studies consider that elasticities may differ in time or / and space. Michinaka *et al.* (2011) group similar countries using cluster analysis, and estimate demand elasticities for each group. They find that clusters with high consumption per capita and low forest coverage have higher price elasticities than other clusters. Brooks *et al.* (1995); Kangas and Baudin (2003); Jonsson (2012) estimate demand elasticities based on time series analyses and separate low income from high income countries. Buongiorno (2015) separates low and high income countries. He concludes that for most product groups, elasticities are not significantly different between low and high income countries, except for plywood and newsprint.

Hetemäki and Kuuluvainen (1992) and Abildtrup and Helles (1998) find non stationary time series of round wood demand in Finland and Denmark respectively. They use cointegration analysis to estimate demand functions. In a panel context, there has yet not been any contribution to this line of research in the relatively small field of forest economics. The rare panel data based study that mentions non-stationarity issues (Hurmekoski and Hetemäki, 2013) considers that the time dimension is sufficiently small so that non-stationarity can be ignored. In contrast,

with consumption data available from 1980 and even from 1961 for 12 countries, we consider that the time dimension is sufficiently long. As a result, non stationarity issues cannot be ignored. The remainder of this article is a first attempt to deal with the implications of non stationarity and spurious regressions on the inference of demand models in a panel context, using recent developments of panel techniques.

3.3. Model and data

A theoretical forest products demand model can be derived from a Cobb Douglas production function (Simangunsong and Buongiorno, 2001):

$$g_{it} = ay_{it}^b z_{it}^c \quad (3.1)$$

with g_{it} industry production in a given country i and year t , y_{it} consumption of forest products and z_{it} consumption of other products. Considering $\beta_1 = 1/(b + c)$ and $\beta_2 = -c/(b + c)$ the cost minimisation problem $\min(y_{it}p_{y_{it}} + z_{it}p_{z_{it}})$ leads to the following demand for intermediate forest products :

$$y_{it} = \beta_0 g_{it}^{\beta_1} \left(\frac{p_{y_{it}}}{p_{z_{it}}} \right)^{\beta_2} \quad (3.2)$$

Model (3.2) is used for example in the GFPM (Buongiorno *et al.*, 2003) and in Chas-Amil and Buongiorno (2000). If the price of other inputs $p_{z_{it}}$ is represented by the GDP deflator, then $p_{y_{it}}/p_{z_{it}}$ is equal to the real price of forest products p_{it} . The demand model, transformed with natural logarithm, becomes:

$$\ln y_{it} = \beta_0 + \beta_1 \ln g_{it} + \beta_2 \ln p_{it} + \epsilon_{it} \quad (3.3)$$

We will explain below (section 3.4.2) how we test for a long term relationship between variables of the demand model by using cointegration tests.

For estimation purposes, a panel dataset is assembled for each of the 12 forest products mentioned in table 3.1. Production and trade volumes are obtained from the FAO forestry production and trade database (Gheri and Kao, 2014). Apparent consumption, measured in cubic meters for sawnwood and wood panels and measured in tons for paper products, is calculated from the production and trade data, in each country i and year t :

$$y_{it} = production_{it} - export_{it} + import_{it}$$

Prices are calculated from the weighted average of import and export prices:

$$p_{it} = (\text{importvalue}_{it} + \text{exportvalue}_{it}) / (\text{importquantity}_{it} + \text{exportquantity}_{it})$$

In line with other models mentioned in the literature section, domestic and foreign products are considered perfect substitutes (in contrast to Sauquet *et al.*, 2011).

Prices are converted to constant US dollar using the US GDP deflator and to constant euros using an exchange rate between the US dollars and a fictive euro currency for the period 1978-1998 (FRED, 2015). Since the exchange rate has a strong effect on the variation of forest products prices labelled in US dollars, price and GDP series should be preferably labelled in euros when analysing European countries. The conversion is only possible from 1978, we therefore retain price and GDP series labelled both in constant dollars (from 1961 to 2013) and in constant euros (from 1980 to 2013) in our dataset.

To obtain balanced panels, countries which have missing data in some years are removed from the dataset. We build three balanced panels with different time dimensions. A first panel dataset starts in 1961 and contains data for 12 countries (N) and over 53 years (T); a second panel starts in 1970 (N=14, T=44) and includes the largest country, i.e. Germany; a third balanced panel starts in 1980 (N=15, T=34) and contains price and GDP series labelled in euros instead of US dollars. Note that the number of countries N actually varies among the various forest products considered, and that we indicate the number N generally present for most forest products in parenthesis in the previous sentence. The third and also shortest panel (N=15, T=34) is the one mainly used in the article for economic readability. Results concerning the 2 other panels are available in annex.

Table 3.1 illustrates two decades of changes in secondary forest products consumption in the EU-28. Major products highlighted in bold are aggregates of the products underneath. For example Total Paper Products is equal to the aggregate of Newsprint, Printing and Writing Paper and Other Paper and Paperboard. For the sake of brevity, tests results are reported for 6 main products only: the three paper products mentioned in the previous sentence plus Sawnwood Coniferous, Particle Board and Fibreboard. These 6 products together represent a very large proportion of the forest products consumed in the EU. Non stationarity tests and the estimation of demand functions are performed for each product individually.

3.4. Methodology

3.4.1. Panel non stationarity tests

As early as 1982, Nelson and Plosser challenge the trend stationarity hypothesis of several macroeconomic time series using Dickey and Fuller (1979) unit root tests.

Table 3.1.: Consumption of industrial forest products in the EU-28.

Product	Yearly consumption				Unit
	1980	1990	2000	2010	
Total Paper Products	42	58	84	85	million T
Newsprint	6	8	11	9	
Printing and Writing Paper	12	19	29	26	
Other Paper and Paperboard	25	31	44	50	
Total Sawnwood	86	88	100	90	million m^3
Sawnwood Coniferous	66	71	84	80	
Sawnwood Non Coniferous	20	18	16	10	
Total Wood-Based Panels	31	37	53	56	million m^3
Particle Board	21	25	34	35	
Fibreboard	4	4	11	12	
Plywood	4	6	6	7	
Veneer Sheets	1	2	2	2	

With an example of “highly significant” regression between the UK consumer price index and cumulative rainfall, Hendry (1980) gives a nice illustration of spurious regressions. He encourages authors using time series regressions to provide additional econometric tests that enable readers to “correctly judge plausibility”.

However, unit root tests based on yearly time series have low power and their implications are limited (Bai and Ng, 2004). Hoping to increase power, some authors (Breitung, 2000; Choi, 2001; Levin *et al.*, 2002; Im *et al.*, 2003; Hadri, 2000) develop various so-called first generation panel unit root tests, extending the time dimension by a country dimension. When the strong hypothesis of cross section independence is not verified, most power gains are due to size distortions (Bai and Ng, 2010). It turns out that macroeconomic time series are often correlated between countries. For instance, France and Germany might have similar consumption trends due to common factors that could bias the results. Hence second generation (Hurlin and Mignon, 2007) panel unit root tests have been created to relax the cross-section independence hypothesis.

Bai and Ng (2004; 2010), deriving the so-called PANIC test, deal with cross section correlation by distinguishing between sources of non-stationarity that are common to all countries (common component) and sources of non-stationarity that are specific to a particular country (idiosyncratic). They develop a pooled test for the null hypothesis of non-stationarity considering the following data generating process:

$$X_{it} = D_{it} + \lambda_i F_t + e_{it} \quad (3.4)$$

Where i and t represent country and time index, D_{it} is a deterministic component and λ_i is a country specific loading factor. This setup makes it possible to capture

the cross section correlation inside a common component F_t . The stationarity of the common component can then be analysed separately from the stationarity of an idiosyncratic component e_{it} . Another issue in macroeconomic series is the presence of structural breaks. Indeed structural breaks can change the distribution of the statistic and can lead to erroneous conclusion regarding the rejection of the null hypothesis. A modified version of the PANIC test takes into account structural breaks and common stochastic trends (Bai and Carrion-i-Silvestre, 2009). We will use both the PANIC and Bai and Carrion-i-Silvestre (2009) tests for comparison and robustness check.

Carrion-i-Silvestre *et al.* (2005) develop another stationarity test that allows for multiple breaks at different time for individual countries. The data generating process of this test is written as follows:

$$y_{it} = \alpha_i + \sum_{k=1}^{m_i} \theta_{ik} DU_{ikt} + \beta_i t + \sum_{k=1}^{m_i} \gamma_{ik} DT_{ikt}^* + \epsilon_{it} \quad (3.5)$$

where α_i is a country specific constant, DU_{ikt} a dummy variable equal to 1 for $t = T_{bk} + 1$ and 0 elsewhere, DT_{ikt}^* a dummy variable equal to $t - T_{bk}^i$ for $t > T_{bk}^i$ and 0 elsewhere with T_{bk} the k -th date of the break for the i -th individual. This test considers structural breaks in the individual trend ($\theta_{ik} \neq 0$), temporal effects ($\beta_i \neq 0$), and temporal structural break effects ($\gamma_{ik} \neq 0$). It is based on the Hadri (2000) test which has a null hypothesis of stationarity. Thus a rejection of this test provides complementary information to the PANIC test.

Panel data which exhibit non-stationarity cannot be analysed with usual regression techniques because estimated coefficients would be spurious. It remains however possible to test if non-stationary variables exhibit common variations, that is if the series exhibit a cointegration relationship.

3.4.2. Cointegration tests and estimation method

In a first stage, panel cointegration tests estimate the existence of a relationship between non-stationary panel variables. In a second stage, if those tests do not rule out cointegration, elasticity coefficients can be estimated.

A range of panel cointegration tests (Kao and Chiang, 1999; Pedroni, 2004) are based on analysing the residuals of a spurious regression. However, these tests make the assumption of independent cross sections and they set common factor restrictions, in other words they assume the short run and long run dynamics to be the same for all series in the panel. Since cross section dependence is likely to occur in the residuals of the relationship between consumption and its covariates, we compute two suitable cointegration tests: Westerlund (2007) and Westerlund and Edgerton (2007). The (Westerlund, 2007) test is based on an error correction model:

$$\Delta \ln y_{it} = \alpha_0 + \alpha_i(\ln y_{it-1} - \beta_1 g_{it-1} - \beta_2 p_{it-1}) + \sum_{j=1}^{p_i} \alpha_{ij} \Delta \ln y_{it-j} + \sum_{j=0}^{p_i} \alpha_{ij} \Delta \ln y_{it-j} + e_{it} \quad (3.6)$$

where α_i is the error correction term, that is the speed of adjustment of the short run to the long run equilibrium relationship between y and its covariates. The test is working by testing if α_i is significant at usual levels. If $\alpha_i = 0$, there is no error correction and thus no cointegration relationship. If $\alpha_i < 0$, the model is error correcting and as a consequence the three variables are cointegrated. Note that leads and lags terms of the difference of $\ln y_{it}$ are included to take into account endogeneity issues. Westerlund builds four statistics incorporating two different classes of tests (group-mean and panel tests): G_a , G_t , P_a and P_t . Group-mean tests are based on weighted sums of the α_i estimated for individual countries (at least one). Whereas the panel tests are based on an estimate of a common α_i coefficient for the panel as a whole, this last class of test is thus less restrictive. Finally, note that G_t and P_t are computed with standard errors of the α_i estimated in a standard way whereas G_a and P_a are based on Newey and West (1994) standard errors adjusted for heterogeneity and autocorrelation. Furthermore, Westerlund employs the bootstrap approach from Chang (2004) making inference possible under cross section dependence. To check the robustness of the Westerlund (2007) results and to go further, we also computed the Westerlund and Edgerton (2007) cointegration test robust to both cross section dependence as well as structural breaks. Westerlund and Edgerton derived a test with common factors assumed to be stationary and allow a shift in intercept and in the cointegration relationship. The second test also uses bootstrap techniques to simulate and reduce distortions due to cross-section correlation between countries.

In addition, changes in the long term relationship can bias conclusions towards accepting the null of no cointegration. Banerjee and Carrion-i-Silvestre (2015) dealt with this issue by providing a test that takes into account structural breaks in the cointegration vector and/or in the common component. The data generating process models eight different variations depending on which assumptions are made about the presence of breaks. From a model with fixed or time effects, assumptions can be relaxed to add breaks in the level of the cointegration vector, in the common trend, or both. In practice, only a very limited number of breaks can be detected.

For those products and variables for which tests do not reject the cointegration hypothesis, estimating regression coefficients remains challenging and requires specific estimation techniques. Pedroni (1996) develops a fully modified OLS (FMOLS) for cointegrated panel data. Then Kao and Chiang (1999) develops a dynamic OLS for cointegrated panel data (DOLS) and shows through Monte Carlo simulations that

it is less biased than the OLS and FMOLS estimators, especially in the case of heterogeneous panels. Hence we use DOLS and the demand model presented equation 3.3 takes the following form:

$$\ln y_{it} = \beta_0 + \beta_1 \ln g_{it} + \sum_{j=-q}^q c_{ij} \Delta \ln g_{i,t+j} + \beta_2 \ln p_{it} + \sum_{j=-q}^q d_{ij} \Delta \ln p_{i,t+j} + \epsilon_{it} \quad (3.7)$$

where past and future values of Δg_{it} and Δp_{it} are added as additional regressors to correct for bias in the cointegrated panel regression. In that equation, q is a finite number of lead and lags that tends to infinity with T (Kao and Chiang, 1999) and c_{ij} and d_{ij} are coefficients of lead or lag of the explanatory variables.

An alternative approach to estimation in the context of non stationarity is the Pool Mean Group (PMG) approach by (Pesaran *et al.*, 1999). In order to simplify the modified demand equation let us have $\ln y_{it}$ represented by y_{it} and $\ln g_{it}$ and $\ln p_{it}$ represented by a vector of explanatory variables X_{it} . The demand model is first assumed to be an autoregressive distributive lag model (ARDL) :

$$y_{it} = \phi_i \sum_{j=1}^p \lambda_{ij} y_{i,t-j} + \sum_{j=0}^q \delta'_{ij} X_{i,t-j} + \mu_i + \epsilon_{it} \quad (3.8)$$

Then equation 3.8 is reparametrized in the form of an error correction model (ECM):

$$\Delta y_{it} = \phi_i y_{i,t-1} + \beta'_i x_{it} + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta^{*'}_{ij} \Delta X_{i,t-j} + \mu_i + \epsilon_{it} \quad (3.9)$$

where $\phi_i = -1 - \sum_{j=1}^p \lambda_{ij}$, $\beta_i = \sum_{j=0}^q \delta_{ij}$, $\lambda^*_{ij} = -\sum_{m=j+1}^p \lambda_{im}$, $j = 1, 2, \dots, p-1$ and $\delta^*_{ij} = -\sum_{m=j+1}^q \delta_{im}$, $j = 1, 2, \dots, q-1$. Short term coefficients $\delta^{*'}_{ij}$ can differ between countries, while long term coefficients β'_i are kept homogeneous. Only the long term coefficients are of interest and will be reported below. The following section presents stationarity and cointegration tests results and demand elasticities estimated with the DOLS and PMG methods.

3.5. Results

Each product's consumption is represented by a panel dataset of 15 countries over 34 years. The consumption, GDP and price variables are first tested for stationarity. Then, for those variables which could be considered non-stationary, we estimate the presence of a cointegration relationship. Results for the 6 major products are presented below.

Table 3.2.: Panel unit root tests of log(consumption).

Item	Breitung	MadWu	LLC	Hadri
Newsprint	0.010	0.370	0.370	0.000
	I(0)	I(1)	I(1)	I(1)
PrintingandWritingPaper	0.410	0.150	0.000	0.000
	I(1)	I(1)	I(0)	I(1)
OtherPaperandPaperboard	0.790	0.000	0.000	0.000
	I(1)	I(0)	I(0)	I(1)
SawnwoodConiferous	0.000	0.030	0.100	0.000
	I(0)	I(0)	I(1)	I(1)
ParticleBoard	0.010	0.610	0.040	0.000
	I(0)	I(1)	I(0)	I(1)
Fibreboard	0.190	0.240	0.070	0.000
	I(1)	I(1)	I(1)	I(1)

Note: p values are reported in the table. LLC means Levin-Lin-Chu test (2002). A non stationary series is not necessarily integrated of order one I(1), but to facilitate table reading, we use I(1) to mean that a unit root cannot be rejected at the 5% confidence level and I(0) in the other case. Except for the Hadri test for which I(1) means that the null hypothesis of stationarity is rejected.

3.5.1. Panel unit root tests

First generation panel unit root tests for the consumption variable are presented in table 3.2. They lead to contradicting results. At least, the null hypothesis of stationarity is rejected by the Hadri (2000) test for all products and all variables: consumption, GDP and prices, but the three other tests reject the null hypothesis of non-stationarity in some cases only and do not reject it in others. Table 3.2 presents tests performed with one lag. The Maddala and Wu (1999) test assumes a null hypothesis that some of the series in the panel have a unit root. It cannot be rejected for any of the product except for other paper and paperboards and for sawnwood coniferous. Tests by Levin-Lin-Chu (2002) and Breitung (2000) assume a null hypothesis that all series in the panel have the same autoregressive parameters. This hypothesis is rejected at the 5% level for the consumption variable for some but not all products. All in all, first generation unit root tests tend to reject the stationarity of the consumption panel variable and to estimate that some - but not all - series in the panel have a unit root. The GDP and price variables not reported in the table above present similar results.

However, as we previously explained in the methodology section, these first generation panel unit root tests are likely to be biased. To this end, we test the cross section dependence of the errors in panel fixed effect demand models. P-values for the Pesaran (2004) diagnostic test are in the range of 10^{-12} to 10^{-9} , thus strongly

Table 3.3.: PANIC (2004) test of H_0 : non stationarity

Product	Consumption		GDP		Price	
	Common	Idiosyncratic	Common	Idiosyncratic	Common	Idiosyncratic
Newsprint	1.07 I(1)	0.91 I(1)	6.20 I(0)	-0.84 I(1)	8.64 I(0)	-1.87 I(1)
Printing and Writing Paper	-0.86 I(1)	0.79 I(1)	5.07 I(0)	-0.41 I(1)	7.65 I(0)	-1.36 I(1)
Other Paper and Paperboard	3.27 I(0)	-2.38 I(1)	6.20 I(0)	-0.84 I(1)	7.12 I(0)	-1.50 I(1)
Sawnwood Coniferous	2.78 I(1)	2.80 I(0)	6.20 I(0)	-0.84 I(1)	3.68 I(0)	-3.52 I(1)
Particle Board	3.30 I(0)	-0.32 I(1)	6.35 I(0)	4.51 I(0)	5.99 I(0)	-2.03 I(1)
Fibreboard	4.99 I(0)	-0.88 I(1)	6.67 I(0)	-0.91 I(1)	8.07 I(0)	0.15 I(1)

Note: Tests performed with a maximum of 4 lags. $T = 34$. The PANIC pooled demeaned test has a critical value of 2.87 at the 5 percent level, a null hypothesis of homogeneous non-stationary is rejected above that value. The pooled idiosyncratic test has a critical value of 1.64 at the 5 percent level.

rejecting the null hypothesis of cross section independence for all forest products. Consequently other panel unit root test which deal with cross section dependence have to be used.

Table 3.3 presents test results performed with a maximum number of common factors equal to 8 and a maximum number of lags equal to 4. I(1) means that the null hypothesis of non-stationarity could not be rejected and I(0) that it could be rejected. Non-stationarity of the consumption variable can be rejected on the common component for some products, but cannot be rejected on the idiosyncratic component. Non stationarity of the GDP variable can be rejected on the common component but cannot be rejected on the idiosyncratic component. It should be noted that country groups differ for each product, that is why the GDP variable is reported multiple times. Finally the price variable has a common component for which non-stationary can be rejected while non stationarity cannot be rejected for the idiosyncratic component. This test based on GDP and prices in constant euros could only be completed based on the series from 1980. When longer time series are tested, starting from 1961 using constant US dollars prices and GDP values, the rejection of H_0 differs slightly depending on the product (see annex, Tables B.1 and B.2).

In annex, we provide the results of another test for the null hypothesis of a unit root in the presence of structural breaks and cross section dependence (Bai and Carrion-i-Silvestre, 2009). Concerning the consumption and GDP variable (Tables B.5 and B.6), the unit root hypothesis is not rejected in most models with constant or trend and for all products. However, concerning the price variable (Table B.7) the unit root hypothesis is rejected for paper products (newsprint, printing and writing paper, other paper and paper board) and it is not rejected for models with trend (2 and 4) for sawnwood and for models with a constant (models 1 and 3) for fibre board and particle board. In the case of sawnwood, it should also be noted that the P and P_m statistics tend to over reject the null when the time dimension is small.

Table 3.4.: Carrion-i-Silvestre *et al.* (2005) test of H_0 : stationarity

Product	Consumption		GDP		Price	
	het	hom	het	hom	het	hom
Newsprint	I(1) 12.41 (0.00)	I(1) 11.72 (0.00)	I(1) 30.64 (0.00)	I(1) 8.65 (0.00)	I(1) 8.32 (0.00)	I(1) 2.56 (0.01)
Printing and Writing Paper	I(1) 26.69 (0.00)	I(1) 7.95 (0.00)	I(1) 31.77 (0.00)	I(1) 8.44 (0.00)	I(1) 2.01 (0.02)	I(1) 4.43 (0.00)
Other Paper and Paperboard	I(1) 8.32 (0.00)	I(1) 5.21 (0.00)	I(1) 30.64 (0.00)	I(1) 8.65 (0.00)	I(1) 2.04 (0.02)	I(0) 0.61 (0.27)
Sawnwood Coniferous	I(1) 8.42 (0.00)	I(1) 9.33 (0.00)	I(1) 30.64 (0.00)	I(1) 8.65 (0.00)	I(1) 7.61 (0.00)	I(1) 3.89 (0.00)
Particle Board	I(1) 11.95 (0.00)	I(1) 6.43 (0.00)	I(1) 30.68 (0.00)	I(1) 10.88 (0.00)	I(1) 9.84 (0.00)	I(1) 6.06 (0.00)
Fibreboard	I(1) 7.05 (0.00)	I(1) 9.64 (0.00)	I(1) 24.47 (0.00)	I(1) 7.24 (0.00)	I(1) 8.01 (0.00)	I(1) 4.39 (0.00)

Notes: p values are indicated in parenthesis. A maximum of 5 structural changes permitted. $T = 34$. Hom and het represent homogenous and heterogenous long-run variance.

Overall, the test by Bai and Carrion-i-Silvestre (2009) confirms that there is a non stationarity issue for most series, also when structural breaks are taken into account.

This is further validated by another test allowing for structural breaks (Carrion-i-Silvestre *et al.*, 2005), which clearly shows that the null of stationarity is rejected for all variables (Table 3.4).

Finally, second generation tests have shown that consumption, GDP and price panel datasets are likely to be non-stationary. This can cause issues for inference, unless a cointegration relationship can be established between forest products demand and its explanatory variables. We test this possibility in the following section.

3.5.2. Cointegration tests

The first test by Westerlund (2007) has a null hypothesis of no-cointegration (table 3.5). It is based on an Error Component Model and uses bootstrap p-values to correct for cross section correlation. H_0 of no-cointegration is rejected at the 5 percent level for printing and writing paper and for fibreboard in the specification with a constant. In the specification with a constant and a trend, H_0 is rejected for one product only: printing and writing paper. H_0 can not be rejected for any other product. Based on the first cointegration test by (Westerlund, 2007) there would be only two products for which inference could be based on a cointegrated vector : printing and writing paper and fibreboard.

The second test by Westerlund and Edgerton (2007), has a null of cointegration for the panel as a whole (table 3.6) and takes into account cross section dependence. When the model includes a constant alone, cointegration is not rejected for any product. However, when the model includes both a constant and a trend, it is rejected at the 5% level for newsprint, other paper and paperboard and sawnwood. To test the relevance of including a trend, we perform a DOLS estimation similar

Table 3.5.: Westerlund (2007) test of H_0 : no cointegration between y , g and p

	Product	G_t	G_a	P_t	P_a
Constant	Newsprint	-0.97 (1.00)	-1.35 (1.00)	-5.61 (0.63)	-4.36 (0.45)
	Printing and Writing Paper	-0.94 (0.90)	-1.73 (0.05)	-5.69 (0.00)	-6.22 (0.00)
	Other Paper and Paperboard	-1.82 (0.73)	-4.61 (0.93)	-6.22 (0.83)	-6.75 (0.97)
	Sawnwood Coniferous	-2.00 (0.67)	-2.93 (0.96)	-6.69 (0.88)	-4.04 (1.00)
	Particle Board	-1.77 (0.58)	-3.40 (0.85)	-5.15 (0.25)	-3.53 (0.19)
	Fibreboard	-3.02 (0.02)	-4.46 (0.03)	-8.31 (0.00)	-4.28 (0.00)
Constant and trend	Newsprint	-1.24 (1.00)	-1.32 (0.98)	-7.00 (0.41)	-4.69 (0.96)
	Printing and Writing Paper	-1.92 (0.74)	-4.05 (0.02)	-7.50 (0.00)	-7.32 (0.00)
	Other Paper and Paperboard	-2.13 (0.90)	-3.78 (0.98)	-4.59 (0.98)	-3.11 (1.00)
	Sawnwood Coniferous	-1.29 (1.00)	-1.82 (0.98)	-5.60 (0.93)	-3.93 (1.00)
	Particle Board	-2.07 (0.73)	-4.17 (0.81)	-6.20 (0.65)	-3.64 (0.62)
	Fibreboard	-1.94 (0.93)	-1.97 (0.96)	-9.36 (0.37)	-4.28 (0.88)

Notes: bootstrap p-values are reported in parenthesis. 1 to 3 lags and leads chosen by AIC (Akaike Information Criterion). (T = 34)

Table 3.6.: Westerlund and Edgerton (2007) test of H_0 : cointegration for the panel as a whole

Product	Constant		Constant and Trend	
	LM_N^+	p-value	LM_N^+	p-value
Newsprint	3.24	1.00	10.40	0.00
Printing and Writing Paper	2.41	0.75	6.41	0.17
Other Paper and Paperboard	1.04	1.00	6.03	0.03
Sawnwood Coniferous	2.48	1.00	7.79	0.02
Particle Board	1.43	1.00	4.60	0.56
Fibreboard	2.11	0.96	3.71	0.20

Notes: bootstrap p-values are reported. Tests are performed with a maximum of 3 lags (T = 34)

to the one presented in table 3.7 with the addition of a trend. It shows a negative coefficient on the trend for most products and although significant, the coefficient has a particularly low value between -0.076 and 0.004. Therefore we reject the presence of a trend for the model of interest. According to the Westerlund and Edgerton test, the consumption, price and GDP variables are cointegrated and there is a long run relationship between them.

Finally, results for the Banerjee and Carrion-i-Silvestre (2015) cointegration test allowing for structural breaks and common factors are reported in annex, Table B.12. We find clear evidence of rejection of the null of non cointegration for sawnwood, using model 6 (a model with both level and cointegration vector shift). Additionally, particle board and other paper and paper board show strong evidence of cointegration using model 2 (a model with individual and time effects only, without breaks). Yet, other results are not clear-cut in favour of cointegration. Accordingly, when structural breaks are taken into account, it appears that evidence for cointegration becomes weaker. This test is however suitable for longer time period (T>50), instead

of the 34 years that were used in table B.12, therefore results should be interpreted with caution. This is supported by the fact that tests performed on longer time period (see Tables B.13 and B.14 in annex) tend to have more rejection of the null hypothesis of no cointegration.

3.5.3. Estimated demand elasticities

The six products analysed in this article present some form of cointegration between the consumption, price and GDP variable. Even though results concerning some products are less clear cut in favour of cointegration, we estimate demand elasticities for all six products. Table 3.7 reports the dynamic OLS for cointegrated panel data and Pool Mean Group estimation results. For comparison purposes, median elasticities obtained in a literature review by Simangunsong and Buongiorno (2001) are reported in the “literature” column. This review of 9 publications is based on pre-2000 forest products panel data sets (with varying number of countries).

Most estimates have the expected sign with a positive GDP elasticity and a negative price elasticity of demand. We find that paper products and fibreboard GDP elasticities are significantly lower compared to those in the literature. GDP elasticities remain lower even in separate estimations performed on pre-2000 data (to benchmark with the literature estimates).

As for price elasticities, they are positive for newsprint and sawnwood, but other products retain a negative price elasticity as expected from economic theory. In addition, estimations performed on the two other panel datasets (briefly described in the data section: $N=12$, $T=53$ and $N=14$, $T=44$) show that estimated price elasticities are less stable than GDP elasticities with respect to changes in the time period and vary considerably in the $[0, -1]$ interval. They remain however almost always negative, as expected by theory. Estimation results for these two additional subsamples are available in a supplementary appendix (Tables B.15 and B.16).

Previous literature based on panel estimates (Least Squares with Dummy Variables, LSDV) in line with Chas-Amil and Buongiorno (2000) for example did not take into account non stationarity issues. Thus, previous elasticity estimates are likely to be spurious. When we take into account non stationarity issues, it is interesting to note that revenue elasticities estimated by DOLS and PMG are significantly lower. Lower revenue elasticities illustrate two main drivers beyond the scope of our model: firstly there is a range of substitute materials on the demand side and secondly forest products supply is constrained. When revenue increases, demand for substitute products increases in parallel. Because supply is constrained, increased demand is met in part by substitute products. The two mechanism combined lead to a lower projected growth of demand as revenue increases.

In order to simulate the implications of modified demand elasticities for scenario analysis, we run a partial equilibrium model using the Global Forest Products Model

(GFPM, Buongiorno *et al.* 2003). In that model, GDP projections follow the IPCC-A1 scenario (Intergovernmental Panel on Climate Change) and prices are determined endogenously by an equilibrium between supply, demand and international trade. All scenarios simulate consumption, production and trade over 20 years, starting from 2012. A base scenario uses demand elasticities from Buongiorno (2015, table 3). Three alternative scenarios have identical input parameters, except that they use demand elasticities from the DOLS and PMG estimations and from the literature review by Simangunsong mentioned above. Products with a positive price elasticity (coniferous sawnwood DOLS estimate and newsprint DOLS and PMG estimate) are not included in the simulation as in that case, the social surplus is unbounded and there is no equilibrium solution. A plot and a table showing the different elasticities are available in annex. Simulations with updated elasticities (Table 3.8) show a 17 to 27 % decrease in paper products consumption and a 53% to 60% decrease in fibre board consumption compared to the scenario using demand elasticities from the literature (figure B.3). By the end of the simulation period, prices decrease by 24% to 46% for paper products and sawnwood and by 17% to 20% for wood panels (figure B.18). It should be noted that elasticities in the GFPM base scenario (Buongiorno 2015) are already closer to some of the DOLS and PMG estimates, therefore differences in consumption are less drastic. Overall simulations show a lower consumption growth than previously expected for material wood products by 2030.

Compared to the EU-Wood scenarios mentioned in introduction (Mantau *et al.*, 2010, page 24), our simulations suggest that decreases in some wood material consumption could compensate part of the increase in fuel wood consumption and other emerging biomass uses. Lower prices would mean that tensions on forest resources would not appear by 2030 but several years later.

3.6. Conclusion

In the context of the bioeconomy, policy makers are stimulating the development of bio-based materials and bioenergy from forests. Potential increases of demand can affect prices and lead to trade-offs where encouraging one sub-sector is at the expense other subsectors. Forest sector modelling provides quantitative insights into policy discussions by simulating impacts on supply, demand and international trade. Yet, for decision makers, a significant road-block remains to establish sound policies. The lack of a robust calibration for demand elasticities make it hard to produce reliable forecasts. Previous panel data analysis of demand used variations of ordinary least squares estimators (Chas-Amil and Buongiorno, 2000; Simangunsong and Buongiorno, 2001; Jonsson, 2012). However, these approaches overlooked non-stationarity issues. In this article we address this challenge and reassess long term demand models for solid wood (sawnwood) and fibre based (wood based panels and paper) products which represent the vast majority of forest products consump-

Table 3.7.: Demand elasticities estimated by the DOLS and PMG methods

Product	DOLS		PMG		Literature	
	GDP	Price	GDP	Price	GDP	Price
Newsprint	0.480 (0.052)	0.019 (0.117)	0.130 (0.087)	0.215 (0.150)	1.02	-0.54
Printing and Writing Paper	0.555 (0.050)	-0.284 (0.127)	0.493 (0.067)	-0.409 (0.084)	1.3	-0.38
Other Paper and Paperboard	0.379 (0.032)	-0.442 (0.079)	0.212 (0.046)	-0.297 (0.072)	1.13	-0.3
Sawnwood Coniferous	0.356 (0.052)	0.663 (0.102)	0.214 (0.107)	-0.366 (0.073)	0.78	-0.35
Particle Board	0.733 (0.099)	-0.247 (0.100)	0.992 (0.161)	-0.178 (0.124)	1.02	-0.14
Fibreboard	0.319 (0.093)	-0.761 (0.183)	0.390 (0.196)	-1.420 (0.147)	1.38	-0.26

Notes: DOLS estimations performed with one lag and one lead. Standard errors in parenthesis. (T = 34)

Table 3.8.: GFPM simulated consumption by 2032 in the EU using different elasticities scenario

Scenario	Unit	GFPM base	DOLS	PMG	Simangunsong
Newsprint		8.8			7.7
Printing and Writing Paper	million T	30.4	30.6	29.8	37.1
Other Paper and Paperboard		54.0	53.7	51.7	71.2
Sawnwood Coniferous		89.7		85.3	102.1
Particle Board	million m^3	36.7	43.9	52.8	53.0
Fibreboard		17.9	12.0	10.1	25.6

Notes: GFPM simulation by 2032 using the 2016 version of GFPM.

tion volume and value. In particular, our results provide an updated input in the calibration of the Global Forest Sector Model, the French Forest Sector Model or the EFI Global Trade Model.

Classical estimations are based on a demand model derived from a Cobb Douglas production function, in which national consumption depends on GDP and prices. Suspecting that time series of forest products demand could have unit roots, we test the consumption, GDP and price variables with first and second generation panel unit root test. First generation tests estimate that some but not all series in the panel have a unit root. Second generation tests which take into account cross section dependence, clearly show that all series are non-stationary. Non-stationary panels would lead to spurious estimations, unless a cointegration relationship is present. We therefore test this relationship with two tests which have opposite null hypotheses. A first test rejects no-cointegration for two products only: printing and writing paper and paper board. A second test doesn't reject the null of cointegration for any product. Although it is weaker for some products than others, there is some evidence of cointegration between the consumption, GDP and price variables. We then estimate the demand model with the DOLS and PMG estimators. For most products, GDP elasticities are significantly lower than the average of previous panel estimates obtained from a literature review. This implies that demand is more constrained than previously thought.

This work will be extended with an analysis of changes in the long term relationship between demand and its explanatory variables. Regime changes are expected to appear at different dates in different countries. For some specific products, a theoretical model could be developed where additional explanatory variables provide a better description of structural changes.

As we detailed in introduction, some authors foresee strong tensions on wood markets as early as 2020 (Mantau *et al.*, 2010) or towards 2030 (Buongiorno *et al.*, 2011). However, our simulations show lower demand and lower prices than previous models from the literature. Accordingly, tensions on the market are likely to happen later than expected. This means that solid wood, panel and paper will compete less strongly over raw material with bioenergy and wood-based chemical products. The relative contributions to emissions reductions of the solid wood, wood fibre, energy and wood-based chemical sectors remain to be assessed. Already, sound policy recommends using recycled products such as harvesting residues and post-consumer wood as raw material for fuel and chemical products. In other words, at the end of life of a building or piece of furniture, solid wood products should be recycled in fibre products and fibre based products can be burned to generate bioenergy. Recycling is commonly practised throughout the forest sector, and it maximises the benefits of substitution and storage effects (Sathre and O'Connor, 2010). Overall, slower increase of demand in the paper, panel and solid wood markets, should leave room for a harmonious development of bioenergy and bio-based chemicals.

Natural resource economists might want to consider a more inelastic demand, with

respect to revenue, in their modelling efforts, but basic assumptions of forest products demand models still hold. If sawnwood, paper or panel revenue elasticities of demand had structurally changed toward inferior goods, then public policies might have ignored competition with these market segments. They might have considered wood products mostly as a source of fuels or biochemicals. However, our results show that demand functions remain that of normal goods. Consequently, scenarios of increased biomass consumption for example in the case of electricity generation from biomass can not ignore fibre and solid wood. Such scenarios should integrate all major forest products in their analysis.

Further, policies seeking to increase biomass consumption should also assess the impact on the forest structure. Solid wood are produced in forests that have long rotations, whereas biomass can be produced in short rotation coppices. A large proportion of Europe's long rotation forests fulfil additional purposes such as recreation or biodiversity protection. A more comprehensive assessment should integrate how long term changes in demand impact forest structures and how forest structures impact biodiversity and rural livelihoods.

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4. Information technology, substitute or complement to paper products demand?

4.1. Introduction

Paper products are used either as graphics paper (newspaper, magazines, books, writing paper) or as packaging and sanitary paper. After an almost continuous rise in graphics paper consumption between 1960 and 1990, a decrease can be observed in many countries in the late 1990ies or after 2000 (Figure 4.1). In several countries, this decrease starts before the 2008 economic downturn, and continues after the recovery, showing that this change is not cyclical but that a more profound, structural change is happening in paper consumption. Whether this decrease is a temporary phenomenon or whether it is due to a more profound change in consumer behaviour remains the subject of debate. As a result of lower paper consumption a number of paper mills have closed in Europe and in North America. Note that reduced consumption is not the only cause, another prominent cause being increased competition from other sources of paper products such as Asia and South America. In this article, we focus on analysing the demand side of paper products markets.

Classical demand models (Chas-Amil and Buongiorno, 2000; Simangunsong and Buongiorno, 2001) are not suitable to describe regime changes because they lead to large forecasting errors in the demand for paper products (illustrated for example by Hurmekoski and Hetemäki, 2013, Figure 4). For this reason, updated demand model have been developed to provide a better description of observed data. The main explanatory variables used to explain these changes are related to Information Technology (IT). One could for example tell a story in which newsprint consumption decreases as the consumption of news over the internet increases. This apparent process of substitution between paper-based and IT-based media consumption is slightly more complex because IT doesn't necessarily influence paper consumption negatively. Indeed for printing paper, we could refine the story by considering different phases in the process. In a first phase, at the beginning of the adoption of computer based information flows, IT is a complement to printing paper. In that phase, increases in computer usage are accompanied by increases in the use of printed paper. Then in a second phase, as mobile information technology becomes ubiquitous enough to alleviate the need for printed material, IT becomes a

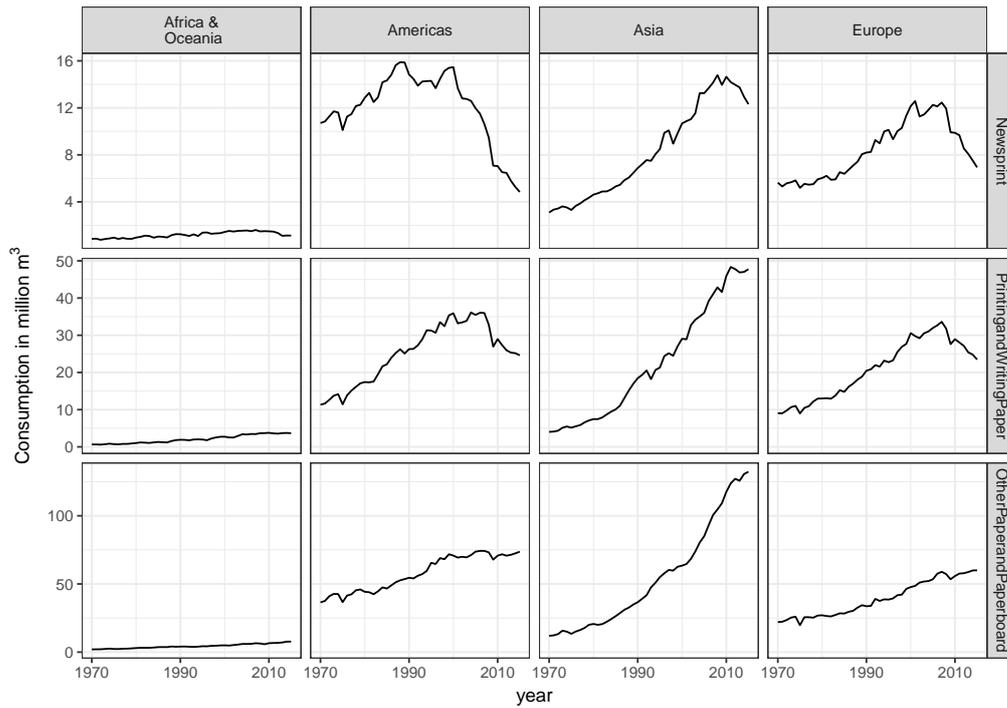


Figure 4.1.: Changes in global paper products consumption by continent

substitute to printed materials. In parallel, packaging paper remains a complement to IT throughout all phases. To illustrate why packaging paper consumption is complementary to IT penetration, one could think for example about the increasing shipment of goods purchased through electronic means. The macroeconomic data on which we will base our analysis is an aggregate of packaging paper, sanitary paper and other products called “other paper and paperboard”. We use this third product as a control sample with the hypothesis that it will not be affected by regime changes.

To summarise, IT’s impact on paper products could be described by one of three dynamics: (1) substitution only, (2) a phase of complementarity followed by a phase of substitution and (3) complementarity only. Several authors describe the structural shift in paper products consumption and suspect it could be linked to information technology. Other authors include various proxies for IT as additional explanatory variables in their model. The contribution of this article is to model and test empirically the use of internet penetration as a threshold variable separating different paper consumption regimes. We first provide an overview of how existing paper products demand models have included the influence of IT. Then we explicit a theoretical mechanism in which consumption thresholds can appear. We describe econometric tests available to investigate the regime change. Then we test the existence of thresholds on a panel dataset of 17 countries over 25 years.

4.2. Literature

A handful of authors investigate the influence of information technology on paper consumption. While some use classical models where national consumption only depends on GDP and prices (Hetemäki and Obersteiner, 2001), others introduce additional variables representing information technology. We will describe the evolution of those modelling approaches. The earliest study by (Zhang and Buongiorno, 1997) uses a two stage Almost Ideal Demand System. In a first stage, income is shared between communication media and other goods. In a second stage the income allocated to communication is shared between printed materials, computers televisions and radios. The study - based on data from 1960 to 1991 - finds no significant effect of computer consumption on paper products consumption. Retrospectively, the result isn't surprising since household access to the internet was in a very early development stage at the time. The internet communication protocol was developed in the seventies. But until the nineties, it was mainly used for emails and files transfer. In fact the technology behind web pages used by today's online media (Hyper Text Transfer Protocol - HTTP) was invented in 1990, just one year before the last data point used in (Zhang and Buongiorno, 1997).

The classical forest products demand model is based on the theory of derived demand. Simangunsong and Buongiorno (2001) explain how demand for intermediate products is derived from a Cobb Douglas Production function. Once transformed with natural logarithm the model typically used for estimation purposes is presented in equation 4.1.

$$\ln C_{it} = \beta_0 + \beta_1 \ln G_{it} + \beta_2 \ln P_{it} + \epsilon_{it} \quad (4.1)$$

Where C_{it} represents the consumption of a product in country i in year t , G_{it} represents the GDP and P_{it} the product's price. Hetemäki and Nilsson (2005) use model 4.1 with an additional lagged consumption variable. Even though information technology is not present explicitly as an independent variable, they still conclude that a structural change is due to the influence of information technology.

Hujala (2011) introduces 4 variables representing information technologies and modifies the demand model as such:

$$\ln C_{it} = \alpha_i + \beta_1 \ln G_{it} + \beta_2 \ln I_{it} + \beta_3 \ln M_{it} + \beta_4 \ln K_{it} + \beta_5 \ln V_{it} + \epsilon_{it} \quad (4.2)$$

Where C_{it} is the paper consumption per capita, I_{it} represents internet users, M_{it} mobile telephone subscribers, K_{it} computers and V_{it} televisions. The price variable is not present in that model. The author considers that the absence of price in the model should not cause a large bias because paper prices represent only a very

marginal proportion of the price of final products. Results show a significant negative effect of the internet penetration rate on newsprint consumption but no significant effect of TV. Office paper demand is positively affected by the number of computers and there is no significant effect of other IT variables.

In a similar approach, Latta *et al.* (2016) introduce internet usage in the following paper demand model:

$$\begin{aligned} \ln C_{it} = & \beta_0 + \beta_1 \ln G_{it} + \beta_2 \ln P_{it} + \beta_3 \ln I_{it} + \beta_4 (\ln I_{it} \cdot \ln G_{it}) \\ & + \beta_5 (D_1 \cdot \ln I_{it}) + \beta_6 (D_1 \cdot I_{it} \cdot G_{it}) + \sum_{i=2,5} \gamma_i D_i + \epsilon_{it} \end{aligned} \quad (4.3)$$

Where $\ln I_{it}$ represents “the logged percentage of the population who use the internet” and $\ln G_{it} \cdot \ln I_{it}$ is an interaction term between GDP and internet use. Then two interaction terms with dummy variables D_1 representing the whole USA and D_j representing US regions. The authors use a two stage least squares estimation with lagged prices as an instrument. Concerning newsprint they found no significant effect of internet penetration, but a significant negative effect of the interaction term between GDP and internet. For printing and writing paper, internet penetration has a positive coefficient while the interaction term between GDP and internet has a negative coefficient. In a follow-up article Johnston (2016) use Latta’s elasticity estimates to simulate future paper consumption under two scenarios: internet adoption converging by 2050 or by 2100.

Hetemäki (1999) reminds us of the usual caveat of such econometric analyses, demand elasticities based on passed data are not suitable to represent future changes. In 1999, he wrote that projections of paper products consumption to 2010 were unlikely to be realistic. As it turned out, actual consumption has exceeded these projections in Asia and Europe. However in the United states these projections have not been reached. But the interpretation of those projections is problematic. Because aggregates contain packaging paper which has a upward trend while printing and writing paper consumption has a downward trend.

Econometric models 4.2 and 4.3 might represent changes happening in the transition period however as the penetration rate of internet users approaches 100%, their fixed coefficients are unlikely to explain a structural change to a new consumption behaviour. Rather than use internet as a variable of the model itself, we want to investigate whether internet penetration can be used as a parameter to explain a non linearity in the demand model. In other words, we would have one paper demand model before the presence of IT and a different model in the presence of IT.

4.3. Theoretical model

Consider an agent maximizing his utility every period. We focus on media consumption and internet connected objects. The agent faces two combined choices: (1) consumption composition, between media consumption (M_t), connected tools consumption (O_t) and a numeraire consumption (X_t); (2) the media consumption composition. The media composition is made of newspaper (N_t), direct internet consumption (I_t) and printed internet consumption (W_t).

We proceed backward in our model resolution. The agent makes his media composition choice:

$$\begin{aligned} \max_{I_t, W_t, N_t} \quad & V_t(I_t, W_t, N_t) \\ \text{s.t. } M_t \geq & P_{I_t}I_t + P_{W_t}W_t + P_{N_t}N_t \end{aligned} \quad (4.4)$$

where V_t is the utility derived from media consumption and M_t are the media expenses. We distinguish media consumption $m_t = I_t + W_t + N_t$ from media expenses $M_t \geq P_{I_t}I_t + P_{W_t}W_t + P_{N_t}N_t$. Thus we consider: $M_t(m_t)$, with $M'_{m_t} > 0$.

The first-order condition brings the optimal media composition (I_t^*, W_t^*, N_t^*) , implicitly defined by:

$$\begin{aligned} \frac{V'_{N_t}}{V'_{I_t}} &= \frac{P_{N_t}}{P_{I_t}} \\ \frac{V'_{W_t}}{V'_{I_t}} &= \frac{P_{W_t}}{P_{I_t}} \\ M_t &= P_{I_t}I_t + P_{W_t}W_t + P_{N_t}N_t \end{aligned} \quad (4.5)$$

Those results are standard: media composition is made in order to equalize marginal rates of substitution and price ratios, and to bind the media budget constraint. One can expect that the marginal utility from internet consumption is increasing in the quantity of connected tools consumed by the agent, but also by the entire economy (working as a positive network externality). Thus we assume that: $\partial V'_{I_t} / \partial O_t > 0$ and $\partial V'_{I_t} / \partial \sum O_t > 0$. From this complementarity, the internet use increases in the media composition as the consumption of connected tools increases $\partial I_t^* / \partial O_t > 0$.

Yet, another complementarity can be underlined as printed internet consumption is conditioned by internet consumption: $\partial V'_{W_t} / \partial I_t > 0$. Then one can expect that printed internet consumption increases with internet consumption $\partial P_t^* / \partial I_t > 0$.

When choosing the consumption composition, the agent maximizes every period his utility subject to a budget constraint (R_t):

$$\begin{aligned} \max_{O_t, X_t, m_t} \quad & U_t(O_t, X_t, m_t) \\ \text{s.t. } R_t \geq & P_{O_t}O_t + X_t + M_t(m_t) \\ \text{s.t. } M_t = & P_{I_t}I_t^* + P_{W_t}W_t^* + P_{N_t}N_t^* \end{aligned} \quad (4.6)$$

The first-order conditions brings the optimal consumption basket O_t^*, X_t^*, m_t^* , implicitly defined by:

$$\begin{aligned} \frac{U'_{O_t}}{U'_{X_t}} &= P_{O_t} \\ \frac{U'_{m_t}}{U'_{X_t}} &= M'_{m_t} \\ R_t &= P_{O_t}O_t^* + X_t^* + M_t(m_t^*) \end{aligned} \tag{4.7}$$

Those results are standard: they show that the consumption basket is chosen in order to (1) equalize marginal rates of substitution and price ratios, and (2) bind the budget constraint. Because of technical progress, that is assumed to be faster in the digital sector, we consider that the marginal utility of connected object is increasing in time, while its price is decreasing in time: $\partial U'_{O_t}/\partial t < 0$; $\partial p_{O_t}/\partial t < 0$. In that case, connected objects consumption increases in time: $\partial O_t^*/\partial t > 0$.

From those two sets of conditions, one can expect possible dynamics of consumption and media composition. Overall, as income increases over time, media and connected tools consumption also increases (as long as they are normal goods, which seems to make sense): $\partial O_t^*/\partial R_t > 0$, $\partial m_t^*/\partial R_t > 0$. Yet, the composition of media demand is changing over time. (1) When connected tools have low dissemination in the economy, the media consumption is essentially composed of newspapers (large N_t^* , low I_t , low W_t): the marginal utility of internet access is low, as well as the one of printing papers; in contrast, the marginal utility of newspaper is higher. (2) At some point, as connected tools become accessible, but do not bring yet a full network externality, internet access can start to get a share of the media composition, but a possibly important share of this is printed (lower N_t^* , higher I_t , higher W_t): there is some substitution between newspaper and internet and printing papers. (3) Once connected objects are largely disseminated in the economy, consumers do not rely much on printed paper any more, as they prefer to benefit from the connected tools network externality (lower N_t^* , higher I_t , lower W_t): here the network externality bring higher marginal utility to internet compared to printing papers.

When focusing on newspaper and printing paper, one can thus expect that their consumption pattern as regard to income depends on internet consumption, with some thresholds. When internet access passes a first threshold ($\overline{I_N}$), the patterns of newspaper demand change: $\frac{\partial N_t^*}{\partial R_t} \Big|_{I_t < \overline{I_N}} \neq \frac{\partial N_t^*}{\partial R_t} \Big|_{I_t > \overline{I_N}}$. When it goes above a second threshold ($\overline{I_W}$), one can also expect a change in printing paper consumption: $\frac{\partial W_t^*}{\partial R_t} \Big|_{I_t < \overline{I_W}} \neq \frac{\partial W_t^*}{\partial R_t} \Big|_{I_t > \overline{I_W}}$.

4.4. Estimation method and data

In a first approach, econometric estimates of structural changes can be obtained by estimating a model before and after a break date. But if the break date is not known,

some method has to be employed to determine the break. Additionally in a panel context where the break date is different for each country, it is important to have a method that reflects individual heterogeneity. One approach is to use an exogenous variable, called a threshold variable and test its influence on the model of interest to divide the model in different regimes. This approach called the panel threshold model (Hansen, 1999), tests whether coefficients are significantly different before and after the threshold. The newspaper demand model reformulated to include a threshold, takes the following form :

$$N_{it} = \begin{cases} \alpha_0 + \beta_{r1}R_{it} + \beta_{p1}P_{it} & , I_{it} \leq \overline{I_N} \\ \alpha_0 + \beta_{r2}R_{it} + \beta_{p2}P_{it} & , I_{it} > \overline{I_N} \end{cases} \quad (4.8)$$

Similarly, the printing and writing paper demand model rewritten as a threshold model:

$$W_{it} = \begin{cases} \alpha_0 + \beta_{r1}R_{it} + \beta_{p1}P_{it} & , I_{it} \leq \overline{I_W} \\ \alpha_0 + \beta_{r2}R_{it} + \beta_{p2}P_{it} & , I_{it} > \overline{I_W} \end{cases} \quad (4.9)$$

Where $\overline{I_N}$ and $\overline{I_W}$ are thresholds on the number of internet users per capita I_{it} , β_{r1} is the coefficient on revenue before the threshold and β_{r2} is the coefficient after the threshold. β_{p1} and β_{p2} are the coefficients on price before and after the threshold respectively. All β coefficients would obviously be different between the newspaper model (4.8) and the printing and writing paper model (4.9). But for the sake of simplicity, β subscripts are kept identical in both equations 4.8 and 4.9. The threshold regression begins by testing the hypothesis of no threshold effect $H_0 : \beta_1 = \beta_2$. This test has a non standard distribution (Hansen, 1999) and therefore critical values have to be obtained by a bootstrap procedure. In practice we test for the presence of one to three thresholds sequentially. Then different coefficients are estimated by OLS between thresholds.

The threshold model gives an abrupt transition from one coefficient to another. But a transition from one demand regime to another regime is likely to happen more gradually. If that is the case, a panel smooth transition regression (PSTR) model by González *et al.* (2005) could be more suitable. The demand function rewritten in the form of a PSTR model would take the following form:

$$C_{it} = \mu_i + \beta_{r1}R_{it} + \beta_{p1}P_{it} + \beta_{r2}R_{it}G(I_{it}; \gamma, c) + \beta_{p2}P_{it}G(I_{it}; \gamma, c) + \epsilon_{it} \quad (4.10)$$

Where μ_i is an individual fixed effect and $G(I_{it}; \gamma, c)$ is a transition function associated with internet users I_{it} , a slope parameter γ and a location parameter c . The

transition function is continuous, bounded between 0 and 1 and follows a logistic specification (González *et al.*, 2005):

$$G(I_{it}; \gamma, c) = \left[1 + \exp \left(-\gamma \prod_{j=1}^m (I_{it} - c_j) \right) \right]^{-1}$$

For $m = 1$, the transition function varies between a low and high regime. Regression coefficients vary along the transition function so that for individual i at time t the regression coefficient on R_{it} is equal to $\beta_{r1} + \beta_{r2}G(I_{it}; \gamma, c)$. When $\gamma \rightarrow \infty$ the transition function takes only two values: 0 when $I_{it} < c$ and 1 when $I_{it} > c$, so that the model becomes equivalent to the threshold model by Hansen. When $\gamma \rightarrow 0$ the model becomes a panel fixed effect linear model. For $m = 2$ the transition function would have a minimum at $(c_1 + c_2)/2$ and be equal to one at low and high values of I_{it} . We will keep $m = 1$ for our purpose to test the influence of internet penetration on paper consumption.

Before estimating the above models, we need to test whether variables in the panel are stationary or not. Several generations of unit root and stationarity tests are available for this purpose. Note that additional caution is required in choosing the test as, in the presence of structural breaks, some unit root tests are biased towards non rejection of the unit root (Perron and Vogelsang, 1992). This structural breaks issue is tackled by the Carrion-i-Silvestre *et al.* (2005) test, based on Hadri (2000), it has a null hypothesis of stationarity. The test has the following data generating process:

$$y_{it} = \alpha_i + \sum_{k=1}^{m_i} \theta_{ik} DU_{ikt} + \beta_i t + \sum_{k=1}^{m_i} \gamma_{ik} DT_{ikt}^* + \epsilon_{it} \quad (4.11)$$

where α_i is a country specific constant, DU_{ikt} a dummy variable equal to 1 for $t = T_{bk} + 1$ and 0 elsewhere, DT_{ikt}^* a dummy variable equal to $t - T_{bk}^i$ for $t > T_{bk}^i$ and 0 elsewhere with T_{bk} the k -th date of the break for the i -th individual. This test allows for structural breaks in the individual trend ($\theta_{ik} \neq 0$), temporal effects ($\beta_i \neq 0$), and temporal structural break effects ($\gamma_{ik} \neq 0$). As a result of this test, if variables of the demand model are considered non stationary, estimation will lead to spurious regressions, unless there is a cointegration relationship between these variables. Therefore, the next step is to perform a panel cointegration test (Banerjee and Carrion-i-Silvestre, 2015) that also accounts for structural breaks and cross section correlation. The test has a data generating process of the following form

$$y_{it} = D_{it} + x'_{it} \delta_{it} + u_{it} \quad (4.12)$$

where D_{it} is a deterministic term, δ_{it} is a cointegration vector and u_t is an error term (see Banerjee and Carrion-i-Silvestre (2015) for the full detail of the data generating process). The deterministic part takes the form:

$$D_{it} = \mu_i + \beta_i t + \sum_{j=1}^{m_i} \theta_{i,j} DU_{ijt} + \sum_{j=1}^{m_i} \gamma_{ij} DT_{ijt} \quad (4.13)$$

where $DU_{ijt} = 1$ and $DT_{ijt} = (t - T_{ij}^b)$ for $t > T_{ij}^b$ and 0 otherwise, $T_{ij}^b = \lambda_{ij}^b T$ is the timing of the j break for the i country. The cointegration vector δ_{it} varies through time. The specification allows for several variations of the model. For example model 1 has no linear trend $\beta_i = \gamma_{ij} = 0$ and a stable cointegration vector $\delta_{it} = \delta_i \forall_i$ so there are only structural breaks in the level of the series. Model 4 also has no linear trend $\beta_i = \gamma_{ij} = 0$, but the cointegration vector is affected by the breaks, δ_{it} varies through time. Other variations of the model relax the different constraints on the stability of the trend and of the cointegration vector. This test allows for different breaks affecting either the deterministic component or the cointegration vector.

Estimations are performed on a panel dataset of all paper consuming countries that have reached at least 80% of internet users in 2015. Production and trade data for newsprint and printing and writing paper is available from FAOSTAT. We calculate the apparent consumption as *production* – *export* + *import*. Prices in each country are calculated as *importvalue* + *exportvalue* / (*importvolume* + *exportvolume*) and expressed in constant US dollars of 2010. An illustration of changes in per capita consumption over 25 years for countries included in the panel is given figure C.1 and C.2. Data on the number of internet users per country come from World Bank (2017) and International Telecommunications Union (2017) estimates. For the purpose of our model, the internet variable varies between 0 and 1 and represents a variation between 0% and 100% of internet users in a population. Internet usage evolution in the 50 largest global consumers of paper products are illustrated figure C.3, advanced internet countries (reaching at least 80% of internet users) are highlighted in blue in the plot.

4.5. Results

We suspect there could be non stationarity issues with the data, therefore we start by performing a panel stationarity test (Carrion-i-Silvestre *et al.*, 2005). Our results (Table 4.1) show that the null of stationarity is rejected in all cases.

Product	Model	Z^*
Newsprint	4	2.24
Printing and Writing Paper	4	-2.30
Other Paper and Paperboard	4	-1.74

Table 4.2.: Banerjee Carrion-i-Silvestre Panel cointegration tests

Table 4.1.: Carrion-i-Silvestre *et al.* (2005) Panel stationarity test

Product	Variable	homogenous	heterogenous
Newsprint	internetc	36.84 (0.00)	239.40 (0.00)
	lcons	16.39 (0.00)	18.48 (0.00)
	lgdprusd	15.71 (0.00)	120.14 (0.00)
	lprice	3.41 (0.00)	6.39 (0.00)
Printing and Writing Paper	internetc	35.81 (0.00)	218.00 (0.00)
	lcons	9.52 (0.00)	47.00 (0.00)
	lgdprusd	35.53 (0.00)	163.91 (0.00)
	lprice	9.16 (0.00)	27.43 (0.00)
Other Paper and Paperboard	itnetuserc	31.73 (0.00)	212.15 (0.00)
	lcons	5.48 (0.00)	20.94 (0.00)
	lgdprusd	17.95 (0.00)	136.09 (0.00)
	lprice	10.75 (0.00)	37.93 (0.00)

Notes: Test of H_0 stationarity. p values are indicated in parenthesis. A maximum of 5 structural changes were allowed.

We then perform the panel cointegration test by Banerjee and Carrion-i-Silvestre. Table 4.2 shows results for a model with individual and time effects and one level shift (model 4), which is a likely model for the data available. Critical values and results for other models are reported in Annex C.1. The null hypothesis of no cointegration is rejected for Printing and Writing Paper and not rejected for the other two products.

Assuming that variables in the panel are co-integrated, we test for the presence of thresholds by using the Hansen (1999) test. According to this test (Table 4.3), the paper demand model reaches a significant threshold once 79% of a population has access to internet. Our hypothesis that newsprint consumption has a lower threshold than printing and writing paper is not verified, both products have the same threshold, at least in this specification. Price and revenue elasticities of printing and writing paper demand are smaller after the last break, although the price elasticity is not significant after the break. The revenue elasticity of newsprint demand is smaller after the break but not significant and the price elasticity has an opposite sign. Other test results for the consumption variable in difference are reported in annex Table C.2. When using differenced variables, newsprint has a first significant threshold at 50% of internet users. As for printing and writing paper consumption,

Table 4.4.: Panel Threshold Regression

Product	Threshold	Variable	Coeff	Std Err	T-Stat	Signif
Newsprint	internet < 79%	lgdp	0.203	0.074	2.74	0.007
		lprice	-0.018	0.093	-0.20	0.844
	internet > 79%	lgdp	0.067	0.082	0.81	0.419
		lprice	0.514	0.109	4.71	0.000
Printing and Writing Paper	internet < 79%	lgdp	0.627	0.051	12.27	0.000
		lprice	-0.358	0.094	-3.81	0.000
	internet > 79%	lgdp	0.556	0.059	9.47	0.000
		lprice	-0.118	0.117	-1.00	0.316

the first threshold is not significant but a second threshold is significant at 53 % of internet users. Estimated coefficients based on differenced variables cannot be interpreted as elasticities, but we can say that they are generally smaller after the last break. We expected there would be no structural change in the consumption of other paper and paper board and we indeed observe that there is no significant threshold for that product both in the specification in level and in difference.

Table 4.3.: Panel threshold test results

Product	Threshold	P-value
Newsprint	0.795	0.003
Printing and Writing Paper	0.797	0.063
Other Paper and Paperboard	0.020	0.707

Note: Critical values are the outcome of 300 bootstrap replications.

Next we estimate a panel smooth transition regression on the same internet user and paper consumption data. Results Table 4.5 show that revenue elasticities are positive and price elasticities are negative as expected by the theory. But for newsprint the price elasticity is not significant. In all cases, price and revenue coefficients associated with the transition function have the opposite sign. β_{r2} is negative, meaning that at the end of the transition the coefficient on revenue $\beta_{r1} + \beta_{r2}$ will be smaller than β_{r1} . The opposite applies for price related coefficients so that the price elasticity $\beta_{p1} + \beta_{p2}$ changes sign and becomes larger in absolute value after the transition phase. The transition function of the Newsprint model has a steep slope coefficient $\gamma = 31$ and a threshold at 80% of internet users, in line with above results of the Hansen model. For the first printing and writing paper model, coefficient on the transition function are explosive. This can be due to the non stationarity of the transition variable itself. In addition, we perform the PSTR with the internet user variable in difference, in that case again change in internet usage has a negative effect on

Table 4.5.: Panel Smooth Transition Regression

Product	Coefficient	Estimate	Std Err	T-Stat	Signif
Newsprint	β_{r1}	0.214	0.071	3.000	0.003
	β_{p1}	-0.037	0.088	-0.425	0.671
	β_{r2}	-0.062	0.035	-1.798	0.073
	β_{p2}	0.195	0.149	1.315	0.189
	γ	31.630	35.240	0.898	0.369
	c	0.803	0.039	20.704	0.000
Printing and Writing Paper (1)	β_{r1}	0.300	0.066	4.525	0.000
	β_{p1}	-0.340	0.084	-4.064	0.000
	β_{r2}	-1.7e+17	6.1e+16	-2.765	0.006
	β_{p2}	5.7e+17	2.4e+17	2.363	0.019
	γ	15.17	8.19	1.85	0.06
	c	3.69	1.00	3.69	0.00
Printing and Writing Paper (2)	β_{r1}	0.264	0.071	3.733	0.000
	β_{p1}	-0.273	0.091	-2.982	0.003
	β_{r2}	-0.083	0.019	-4.446	0.000
	β_{p2}	0.309	0.073	4.263	0.000
	γ	8637.49	6774.25	1.28	0.20
	c_1	0.01	0.03	0.54	0.59
	c_2	5.34	3.97	1.34	0.18

the revenue elasticity and a positive effect on the price elasticity. The transition function has a very steep slope and there are two meaningless thresholds one at 1% and another at 530% of in internet users. But a transition variable in difference is harder to interpret, it would mean that these effects disappear once internet usage reaches a stable stage.

As a last robustness check, we estimate the model before and after an aggregated break date chosen in the year 2000. Because panels are non stationary, we use the Dynamic Ordinary Least Square (DOLS) estimator which is less biased than the OLS estimator for cointegrated panel data (Kao and Chiang, 1999). Revenue and price elasticities have the expected sign (Table C.4). For all 3 products, after the break, revenue elasticities appears unchanged, but price elasticities change to approximately double their pre-break value. Choosing a later break date in 2006 leaves similar elasticities as over the 2001-2015 period, although the use of this estimator on such a small number of years starts to become questionable. DOLS estimation performed with a dummy variable representing the 2008 financial give similar results. In addition we perform PMG estimates over the same sub samples of data. Those results are reported in annex Table C.5. Before the break, price and revenue elasticities have the expected sign, but after the break this is not the case. Newsprint revenue elasticity is negative after the break, which could be interpreted as if newsprint has become an inferior good. For all products, price elasticities are

very unstable. It may be due to the fact that we used series labelled in constant US dollars and that the exchange rate varies differently for each country throughout the period. At last, it should be noted that in 2006 only 5 countries have reached the 80% internet penetration rate (Table C.6), in other words the majority of countries still haven't undergone full transition yet according to the above threshold and transition models.

4.6. Conclusion

With graphics paper demand decreasing in many countries, demand models from the 1990ies generate consumption forecasts that are much too high compared to observed post 2000 data. Previous studies on the structural change had either estimated two demand models before and after a break date or used proxies for information technology directly as explanatory variables in linear panel regressions. We investigate whether the internet penetration rate in a population can be used as a threshold variable. Observing that paper demand doesn't decrease immediately after the adoption of new information technologies, we make the hypothesis that there could be a phase of complementarity where graphics paper consumption rises as the number of internet users rises and a phase of substitution where graphics paper consumption decreases as the number of internet users continues to rise. For this purpose we test for a fixed threshold separating two different models or a smooth transition from one model to the next.

Before performing the estimation we test for non stationarity issues because they could lead to spurious regressions. We notice that the Carrion-i-Silvestre *et al.* (2005) test - a test that allows for the presence of structural breaks - rejects stationarity in all cases. In addition, the Banerjee and Carrion-i-Silvestre (2015) test shows weak evidence for cointegration for printing and writing paper. We then move to the estimation using two methods, first an abrupt threshold and then a smooth transition. The threshold model by Hansen (1999) is general enough to allow different break dates by country. Significant breaks in the consumption of graphic paper occur once around 80% of a country's population has access to internet. When using differenced variables for the estimation we find a different threshold at 50% of internet users. In both cases there is no significant break for other Paper and Paper Board which is what we expected because packaging and sanitary paper are not affected by changes in information technology. The main regression result is that in general revenue elasticities of demand are smaller after the break. Similar conclusions can be drawn from the PSTR where the transition function coefficient shows a dampening effect on newsprint consumption, associated with a 80% threshold. For printing and writing paper, the transition has not fully developed yet and estimates are likely to improve as new data become available. At this stage, our results assert the presence of a threshold effect even if its size is not robust. Hypothesis made in introduction were not all verified, but the penetration rate of internet in the population proves a

promising and parsimonious way to add a new exogenous variable in paper demand models. The transition mechanism is also likely to provide insights for forecasts of paper products demand in developing countries where the internet penetration rate is still growing.

Information technology is certainly not the only factor affecting paper consumption. Some important questions remain open. For instance, it is unclear to what extent consumers environmental awareness also affect their paper consumption. Environmental awareness is likely to have a smaller effect than the use of information technology, or it could be a complementary effect. It would be interesting to explore the relative importance of those 2 effects, although it will probably require different methodologies. At last an important question remains for policy analysis based on paper demand forecasts: for how long will paper consumption reduce, will there be a rebound effect?

5. Conclusion

Forest Sector Models provide insights into future market developments for a wealth of policy relevant scenarios such as climate change mitigation, illegal logging or international trade agreements. But estimating the potential effect of a policy requires reliable forecasts of future consumption. Graphic paper consumption forecasts for example are considered far too optimistic (Hurmekoski and Hetemäki, 2013) and there has been a research gap on this issue since Toppinen and Kuuluvainen (2010) showed that there was a lack of multi country econometric analysis at the European level. This thesis work contributes to a better understanding of forest products demand patterns. The first chapter sets the context and the subsequent three chapters explore the use of forest sector models, the estimation of their demand functions based on recent panel data cointegration techniques and the estimation of non linearities by adding an additional threshold variable.

The second chapter studies the impact of international trade policies on a particular sector of the economy. Macroeconomic impacts predicted from a general equilibrium model (Felbermayr *et al.*, 2013a) are inserted into a forest sector model. The Global Forest Sector Model (Buongiorno *et al.*, 2003) shows that comprehensive tariff elimination would have little effect on the forest sector. However, with deeper reforms and integration, consumption would increase twice as much in percent in the USA as in the EU. Net trade would decrease in the USA more than in the EU while it would increase in Asia. Consumers and producers' welfare would increase in the EU and in the USA, but decrease in some third countries, especially in Asia. Towards the end of chapter two, a sensitivity analysis performed by changing demand elasticities by plus or minus one standard error, results in a change in global forest products consumption that is ten times higher than the effect of the trade agreement. This sensitivity analysis motivates further study of forest products demand functions.

The third article explores new ways to characterise long term demand dynamics in a panel of European countries. Focused on solid wood, panel and paper products, the analysis uses a classical demand model where national consumption depends on real Gross Domestic Product and real prices. In contrast to previous panel estimations in the literature, I highlight the fact that non stationarity time series can lead to spurious regressions. These non stationarity and cointegration issues have been dealt with in a time series setting (Abildtrup and Helles, 1998) but not yet in a panel setting. I use recent panel cointegration techniques to investigate the issue. Cointegration is present for printing paper and fibreboard, though less clear cut for other products. Then I estimate demand elasticities and find that GDP elasticities

are significantly lower than estimates from the literature. Finally, I simulate the implications of modified demand elasticities by using a partial equilibrium model of the forest sector (GFPM, Buongiorno *et al.*, 2003). For most products, changes in elasticities would lead to lower projected demand and lower prices over a 20 years time horizon. Lower solid wood and wood fibre demand would lead to less tensions with wood biomass markets. In a context of rising interest for bio-based products, updated long term demand models contribute to the analysis of the forest sector's sustainability.

Chapter 4 is an attempt to describe structural changes by using a threshold variable. I investigate how the penetration rate of Information Technology (IT) in a population can play a part in a structural change of newsprint and printing and writing paper consumption. A theoretical model of media consumption composition was developed to describe slightly counter-intuitive transition mechanisms. As IT penetration increases past a certain threshold, newsprint consumption starts decreasing. But Printing and writing paper require a greater penetration of IT for network externalities to fully develop. Thus printing and writing paper consumption continues to increase until a higher threshold, after which its consumption reduces too. I test the existence of such thresholds on a panel of 17 countries over 25 years. I find significant thresholds in the consumption model once 80% of a population has access to internet. Yet the thresholds are identical for newsprint and printing and writing paper and the hypothesis of distinct threshold is not verified. Elasticities tend to be smaller after the regime change even though it is the price elasticity that captures most of the effect. As, expected, the presence of thresholds is rejected for packaging and sanitary paper. These results can be taken into account by forest sector modellers who could use the proportion of internet users as an exogenous variable to determine break dates in graphic paper demand.

At a macroeconomic level, practitioners prefer to have simple demand forecasting tools, but no simpler than necessary. This thesis contributes to the reassessment of existing models and introduces an original way to model the structural change in paper products demand. Upgraded demand models are only the beginning of further work on various policy relevant scenarios. Under a new demand structure, forecasts and policy recommendations are likely to change. They are likely to play a role in discussions. As the interest for the bioeconomy rises and a number of products formerly made from fossil fuels get produced from biomass, forest sector models will remain crucial to assess price, demand supply and international trade development within which the bioeconomy can develop itself.

I plan to extend demand and trade modelling work by exploring several other methodologies. To model changes in the trade balance of paper and other fibre-based products, I would like to use a gravity model of trade to compare the relative impact of changes in consumption practices on the one side and of the availability of fast growth plantation outside the EU on the other side. Based on earlier work where I explored discrepancies in bilateral trade data, I would also like to assess changes in trade flows between preferred trade partners of tropical timber. Policy

makers are interested in estimating the impact of illegal logging regulations on trade displacement.

In another extension of this work, I would like to continue assessing drivers of forest products demand with entirely different methods. I am interested in conducting a survey of wood buyers in the construction and furniture industry. I would like to evaluate how they determine their preferences along several axes. A first axis would analyse the preferences for foreign versus local sourcing of forest products. Another axis would analyse the preference for solid wood versus engineered wood products. Yet another axis could concern substitute products. Wood products buyers are the agents deciding upon international trade flows. They possess technical knowledge about the intrinsic quality of products which are the reason for purchasing them in a particular country. This knowledge should provide new insights to refine trade models.

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A. Résumé détaillé en français

La consommation de bois dans l'Union européenne a été estimée à 550 millions de m^3 en 2010 (Mantau *et al.*, 2010). Avec une population de 500 millions d'habitants, chaque citoyen de l'UE consomme un peu plus de $1m^3$ de bois par an. Une question centrale reste liée à tous les enjeux de politiques forestières: les ressources forestières continueront-elles à répondre à la demande de produits forestiers? Dans mes recherches, j'analyse le côté demande de cette question. Diverses formes de politiques économiques peuvent aider à soutenir l'approvisionnement des produits forestiers à long terme. Pourtant, tous ces développements nécessitent des investissements et les prévisions de demande sont essentielles pour prendre des décisions d'investissement. Comprendre les changements à long terme dans la consommation de bois est une préoccupation importante pour les investisseurs privés et publics. Ces développements intéressent également les chercheurs travaillant sur les ressources naturelles si ils veulent suivre le plus important matériau renouvelable en termes de volume global consommé. Cette thèse est composée d'un chapitre d'introduction et de trois articles. Pour le premier article publié dans *Journal of Forest Economics*, j'ai réalisé les simulations et j'ai rédigé l'introduction, la revue de la littérature, l'interprétation des résultats et la conclusion. Mes coauteurs ont conçu et participé à la rédaction de partie théorique¹. J'ai rédigé les deuxièmes et troisièmes articles. Le deuxième article est en cours de révision dans une revue d'économie. Le troisième article a été présenté en conférence à Ulvön, Suède et Freiburg, Allemagne.

A.1. Contexte et méthodes d'analyses de la consommation de produits bois

Les modèles de secteur forêt bois sont basés sur la théorie de Samuelson (1952) décrivant l'équilibre spatial entre offre, demande et commerce international. Elle sert de base théorique éprouvée à plusieurs modèles en équilibre partiel du secteur forêt bois. Il existe des modèles globaux dans lesquels les entités spatiales sont des pays et des modèles nationaux dans lesquels les entités spatiales sont des régions. A l'échelle globale, on trouve par exemple le Modèle Global des Produits Forestiers (GFPM) et le Modèle Global du Secteur Forêt-Bois de l'Institut Européen des Forêts

¹C'est pourquoi j'utilise le pronom «nous» pour décrire le deuxième chapitre, et le pronom «je» ailleurs.

(EFI-GTM). A l'échelle nationale, on trouve par exemple le modèle du Secteur Forêt-Bois Finlandais (SF-GTM) et le Modèle du Secteur Forêt Bois Français (FFSM).

Un équilibre spatial est calculé sur une période de temps fixe, typiquement une année y . S'y ajoute une composante dynamique qui décrit l'évolution de l'offre de bois, de la demande de produits finis et des coûts de production de l'année y à l'année $y+1$. Un nouvel équilibre est calculé à l'année $y+1$. Cette succession de phases dynamiques est statiques se nomme modèle dynamique récursif.

Dans ces modèles en équilibre partiel, une fonction objectif maximise le surplus global sous la forme suivante:

$$\max \left(\sum_{i,k} \int_0^{D_{i,k}} P_{ik}(D_{ik}) dD_{ik} - \sum_{i,k} \int_0^{S_{i,k}} P_{ik}(S_{ik}) dS_{ik} - \sum_{i,k} \int_0^{Y_{i,k}} m_{ik}(Y_{ik}) dY_{ik} - \sum_{i,j,k} c_{ijk} T_{ijk} \right) \quad (\text{A.1})$$

Avec i et j les pays, k les produits, P les prix, D la demande, S l'offre de matières premières, Y la quantité fabriquée, m les coûts de fabrication, T la quantité transportée et c les coûts de transport. Les flux de produits à l'intérieur de ce modèle sont contraints par un bilan matière:

$$S_{ik} + Y_{ik} + \sum_j T_{jik} = D_{ik} + \sum_n a_{ikn} Y_{in} + \sum_j T_{ijk} \quad \forall_{i,k} \quad (\text{A.2})$$

c'est à dire que la demande est égale à l'offre pour tout pays et tout produit, avec a_{ikn} la quantité de bien k nécessaire à la production d'une unité de bien n . La figure 1.7 illustre les liens entre matières premières et produits secondaires.

J'ai d'abord utilisé le modèle GFPM pour simuler l'impact d'un accord commercial sur le secteur forêt bois mondial. Suite à ces travaux, une analyse de sensibilité montrait qu'un changement d'élasticités de demande créait une incertitude sur la demande dix fois supérieure à l'effet de l'accord commercial estimé. C'est pourquoi je me suis intéressé particulièrement aux fonctions de demande situées dans ces modèles. Les estimations économétriques des fonctions de demande sont typiquement réalisées sur des données de panel incluant plusieurs années et plusieurs pays. Simangunsong and Buongiorno (2001) a comparé une dizaine d'études estimant les élasticités de demande en produits bois. L'ensemble des études précédentes considère que les séries sont stationnaires or il se trouve que lorsque la dimension temporelle augmente, on ne peut plus ignorer les problèmes de non stationnarité. J'ai donc cherché à les prendre en compte dans le troisième article de cette thèse. De plus, les fonctions de demande couramment utilisés dans les modèles de secteur forestier entraînent d'importantes erreurs de prédiction dans la consommation de papier, car

elles ne permettent pas de décrire un changement structurel. C'est ce à quoi je me suis attelé dans le quatrième article. J'y explore l'influence de la pénétration des technologies de l'information dans un pays sur sa consommation de papier.

A.2. Impact Potentiel d'un Accord de Partenariat Transatlantique sur le Secteur Forestier Mondial

Les États-Unis et l'Union européenne représentent ensemble plus de 45% du PIB mondial en valeur nominale et 38% en termes de parité de pouvoir d'achat (World Bank, 2013). L'investissement direct étranger est intense entre les deux régions et plus d'un tiers du commerce est constitué par des échanges intra-entreprises entre des filiales de sociétés établies à la fois dans l'UE et aux États-Unis (EC-Trade, 2013). Dans le secteur forestier, l'Union européenne et les États-Unis représentent environ 40% de la production mondiale de bois rond industriel, de sciages, de papier et de carton et de 30% de la production mondiale de panneaux (FAO, 2012).

Les pays qui souhaitent approfondir leurs liens commerciaux se tournent désormais vers des accords bilatéraux ou régionaux car les négociations à l'Organisation Mondiale du Commerce ne progressant plus depuis plusieurs années. Ce mouvement participe à la création d'accords de libre échange dit préférentiel. Ces accords rompent avec le principe de l'Organisation Mondiale du Commerce qui stipule qu'un pays membre ne doit pas avoir de pays partenaire privilégié. Les cycles de négociation concernant un accord transatlantique entre l'Union Européenne et les États-Unis ont commencées dès 1995. Selon les périodes, l'accord est appelé TAFTA - Transatlantic Free trade Area or TTIP - Transatlantic Trade and Investment Partnership. Les accords visant à supprimer les barrières commerciales cherchent à réduire les pertes sèches et à accroître les gains sociaux nets du commerce international.

L'accord TTIP a fait l'objet de plusieurs études testant ses effets sur l'économie. Dans cet article nous nous sommes basés sur les analyses de Felbermayr *et al.* (2013a) qui donnent des estimations de l'impact total du TTIP sur le PIB pour les États-Unis, les 27 pays de l'Union européenne et 98 pays du reste du monde. L'impact d'une simple réduction des droits de douane est négligeable. Les droits de douane sont déjà très bas dans le modèle GFPM. Nous montrons que l'impact d'un accord plus profond qui réduirait les barrières non douanières est légèrement contre-intuitif. Le surplus des producteurs et des consommateurs diminue dans les pays asiatiques. L'augmentation de consommation dans les pays de l'UE et aux USA conduit à une augmentation des importations en provenances de pays tiers, notamment les pays asiatiques. Le résultat principal de cet article montre les effets potentiels de l'accord sur la détérioration de la balance commerciale au profit de pays tiers qui ne prennent pas part à l'accord. Ces effets sur les pays tiers devraient être pris en compte dans l'évaluation de l'impact des accords commerciaux.

Un autre résultat intéressant pour la suite concerne une analyse de sensibilité réalisée

pour estimer l'effet d'un changement d'élasticité revenu. Un changement d'élasticités de plus ou moins un écart type a un effet sur la demande largement supérieur à l'effet de l'accord commercial qu'on cherche à estimer. Ce constat justifie en partie les analyses réalisées dans les 2 articles suivants pour ré-estimer les élasticités de demande en produits bois.

A.3. Réévaluer la demande de produits forestiers en Europe à l'aide d'une approche par cointégration en panel

Entre 1960 et 2000, la consommation de papier et de carton a augmenté de 20 millions à 80 millions de tonnes dans les pays membres de l'UE. La consommation de sciages a oscillé autour de 80 millions de m^3 par an sur la même période. Alors que la consommation de panneaux de bois a augmenté de 10 à 50 millions de m^3 (figure 3.1). Cet article analyse les usages du matériaux bois et n'analyse pas la demande de biomasse pour des usages énergétiques. En se concentrant sur les trois dernières décennies, le tableau 3.1 illustre une grande variation des modes de consommation. Entre 1980 et 2000, on a observé une augmentation générale de la consommation pour tous les produits forestiers dans les pays membres de l'UE, à l'exception des sciages non conifères. Entre 2000 et 2010, la consommation de papier d'impression, de papier journal et de sciages a diminué de façon notable alors que la consommation des autres papiers et cartons (utilisés principalement pour l'emballage) et la consommation de panneaux de bois ont continué d'augmenter, bien qu'à un rythme plus lent que la décennie précédente. Ces changements dans la consommation des produits forestiers peuvent être liés aux cycles économiques des pays analysés et/ou aux changements structurels dans les pratiques de consommation. En d'autres termes, la demande en produits forestiers se développe ou se contracte avec le reste de l'économie, mais aussi suivant sa propre dynamique. Pour mieux appréhender ces phénomènes, les économistes tentent de les modéliser.

Les données concernent 6 produits forestier: papiers journaux, papiers d'impression, papiers d'emballage, sciages résineux, panneaux de particules et panneaux de fibres, dans 15 à 18 pays européens sur une période de 34 ans. J'ai converti les prix en euros constant en utilisant un taux de change fictif basé sur un panier de monnaies entre 1980 et 1998. J'ai aussi travaillé avec 2 autres panels dans lesquels les variables PIB et prix sont exprimés en dollars constant. Un premier panel de 1960 à 2013 et un deuxième de 1970 à 2013 permettant d'inclure l'Allemagne, le plus gros pays consommateur (résultats inclus en annexe). L'ensemble de ces données sont des panels cylindrés c'est à dire qu'un pays est inclus seulement s'il y a des données pour toute la série.

L'utilisation des données de panels permet d'augmenter le nombre d'observations et devrait augmenter la précision des élasticités estimées. Mais les panels longs

(typiquement supérieurs à 15 ans) incluent les difficultés des séries temporelles. Ainsi les problèmes de non-stationarité doivent être pris en compte. A ce sujet, Hendry (1980) donne un exemple de régression fallacieuse mais "très significative" entre l'indice des prix à la consommation au Royaume-Uni et les précipitations cumulées. Il encourage les auteurs qui estiment des modèles basés sur des séries temporelles à fournir des tests économétriques supplémentaires qui permettent aux lecteurs de «juger correctement la plausibilité» des résultats. Un processus est dit non stationnaire lorsqu'il garde mémoire des déviations passées, c'est à dire qu'après un choc, il ne retourne pas à la moyenne ou à la tendance observée. Un des premiers tests développé par Dickey and Fuller (1979) considère que les observations sont générées par un processus autorégressif de la forme $y_t = \rho y_{t-1} + e_t$ où y_0 est une constante et e est une variable aléatoire de distribution normale. Il teste l'hypothèse d'une racine unitaire: $\rho = 1$ qui, si elle est vérifiée, permet de savoir qu'on peut différencier la série pour obtenir des observations stationnaires. En panel, l'ajout de la dimension en coupe transversale augmente le nombre d'observations et donc la puissance des estimateurs mais elle pose de nombreux autres problèmes auxquels plusieurs tests tentent de répondre. Une première génération de tests ne prend pas en compte les problèmes de dépendance en coupe transversale. Or le test de Pesaran (2004) rejette fortement l'hypothèse d'indépendance entre les pays. J'utilise des tests de racine unitaire dit de deuxième génération qui tiennent compte de l'interdépendance entre pays. Ces tests (Bai and Ng, 2004; Carrion-i-Silvestre *et al.*, 2005) montrent que les séries de consommation, prix et PIB sont non stationnaires. Lorsque les séries sont non stationnaires, les coefficients estimés par régressions linéaires sont fallacieux. C'est à dire qu'on ne peut rien dire de la relation entre la consommation de produits bois et ses variables explicatives. Il reste possible d'estimer les fonctions de demande si l'ensemble des variables non stationnaires co-évolue dans une relation de long terme qui est stationnaire entre les variables, on parle de cointégration. Je teste la présence de cointégration entre les variables consommation, PIB et prix. L'hypothèse nulle d'absence de cointégration par le test de Westerlund est rejetée pour 2 produits (Westerlund, 2007). La présence de cointégration n'est pas rejetée pour aucun produit (Westerlund and Edgerton, 2007). Considérant que les variables consommation, PIB et prix sont cointégrés, j'estime les élasticités prix et revenu de la demande avec les estimateurs Dynamic Ordinary Least Square (DOLS) et Pool Mean Group (PMG). L'avantage de l'estimateur PMG est qu'il permet d'avoir des coefficients de court terme différents pour chaque pays, seul le coefficient de long terme, commun à tous les pays nous intéresse.

La plupart des estimations ont le signe attendu avec une élasticité revenu positive et une élasticité-prix négative. Nous constatons que les produits de papier et les élasticités du PIB sont sensiblement inférieurs à ceux de la littérature. Les élasticités du PIB restent inférieures même dans les estimations séparées effectuées sur les données antérieures à 2000 (pour comparer avec les estimations de la littérature). En ce qui concerne les élasticités-prix, elles sont positives pour le papier journal et les sciages, mais d'autres produits conservent une élasticité prix-négative comme prévu

par la théorie économique. J'introduis ces élasticités dans le modèle Global des Produits Forestiers (GFPM). Par rapport à un scénario utilisant d'autres élasticités obtenues dans la littérature, la baisse des coefficients estimés conduit à une baisse de la consommation sur un horizon de 30 ans.

Les modèles de secteur forêt-bois sont un outil important de support à la politique publique, les fonctions de demande représentant le lien entre l'industrie basée sur les produits forestiers et reste de l'économie. J'ai montré que les modèles ne prennent pas en compte les problèmes de non stationnarité. La mise à jour des ces modèles par des élasticités plus robustes permettra la mise à jour des modèles de secteur forêt-bois.

A.4. Les technologies de l'information, complément ou substitut de la demande de papier?

Dans le troisième chapitre, je poursuis l'analyse des déterminants de la demande en m'intéressant plus particulièrement aux changements structurels dans la demande de papiers d'impression et d'écriture. Il se trouve qu'après avoir augmenté sans cesse entre 1960 et 2000, la demande de papier journal et de papier d'impression diminue fortement dans l'ensemble des grands pays consommateurs depuis l'an 2000 et retourne au niveau de consommation de l'année 1980. Ce changement précède la crise économique de 2008. Il ne s'agit pas uniquement d'un changement conjoncturel. J'observe l'influence d'une augmentation d'usage des Technologies de l'Information et de la Communication (TIC). Dans un premiers temps (1980-1990), la consommation de papier est importante et l'usage des TIC est minimal. Lorsque l'utilisation des TIC augmente (1990-200), la consommation de papier continue d'augmenter dans un premier temps. Puis lorsque les TIC sont suffisamment diffusés parmi les consommateurs (après 2000), la consommation de papiers d'impression et de papier journal diminue. Les dates mentionnées entre parenthèse varient en fonction des pays. Je décris un mécanisme de substitution entre la consommation de papier et l'usage des TIC. Au delà d'un certain seuil d'utilisation des TIC (représenté par le nombre d'usager d'internet) la consommation de papier diminue.

Les données concernent un panel cylindré des 50 premiers consommateurs mondiaux de papier. Je me suis intéressé à 2 produits, soit les papiers journaux et les papiers d'impression et d'écriture par opposition aux papiers d'emballage, ces deux produits sont parfois groupés sous l'appellation «papiers graphiques» (Hetemäki, 1999).

Comme au chapitre précédent, le test de stationnarité de Carrion-i-Silvestre *et al.* (2005) montre que les séries de consommation, de PIB et de prix sont non stationnaires. Les résultats du test de cointégration de Banerjee and Carrion-i-Silvestre (2015) rejettent l'hypothèse de non-cointégration pour le papier d'impression et d'écriture, par contre l'hypothèse n'est pas rejetée pour les autres produits. Je suppose que les variables sont cointégrées afin de pouvoir estimer le modèle en niveau,

mais je vais aussi estimer le modèle en différence première. Je teste la présence de seuils dans la consommation de papier avec le test de seuil pour panels non dynamiques développé par Hansen (1999). Ce test est suffisamment flexible pour permettre de dates de breaks différents dans différents pays. Les résultats du test montrent que les modèles de consommation de papiers graphiques atteignent un seuil significatif lorsque 79% d'une population a accès à internet. Par contre les seuils sont identiques. Ainsi l'hypothèse que les seuils soient différents pour le papier journal et le papier d'impression n'est pas vérifiée. L'estimation en différence première montre un seuil à 50% d'utilisateurs d'internet pour les papier graphiques. Dans tous les cas les élasticités prix et revenu sont plus faibles après le seuil, bien qu'elles ne soient pas significatives. Pour le modèle en niveau comme en différence, il n'y a pas de seuil significatif pour les cartons et papiers d'emballage. Les coefficients estimés varient brutalement au passage du seuil. Mais il est peut-être plus réaliste d'estimer un modèle à transition lisse pour lequel les coefficients suivent une fonction de transition González *et al.* (2005). Lorsqu'on estime ce modèle on retrouve un seuil à 80 % d'utilisateurs d'internet. Pour le papier journal, la pente de la fonction de transition est très raide et les coefficients sont de nouveau inférieurs après le changement structurel. Pour le papier d'impression et d'écriture, les coefficients de la fonction de transition sont explosifs après le seuil. Il est important de noter qu'en 2006 seuls 5 pays ont atteint un taux de pénétration d'internet de 80%. Il est probable que les résultats changent lorsque les données disponibles après le seuil auront augmenté.

Cet article apporte donc une première tentative d'estimation d'un changement structurel dans la consommation de produits papiers. La variable de seuil est le pourcentage d'utilisateurs d'internet dans la population d'un pays donné. Les résultats montrent que les élasticités revenu et prix de la demande ne sont pas les mêmes avant et après un changement structurel qu'on peut décrire par un taux de pénétration de 80% d'utilisateurs d'internet dans la population. Ces résultats trouvent une application dans les modèles de secteur forêt-bois. Dans ces modèles, le nombre d'utilisateurs d'internet pourrait être utilisé comme seuil exogène déterminant une date de changement de l'élasticité revenu de la demande de papier.

Les modèles de secteur forêt bois continuent d'être utilisés pour apporter une analyse quantitative sur des sujets aussi divers que l'influence du changement climatique, le commerce illégal du bois, les accords commerciaux, le changement technologique. Au niveau macroéconomique les modèles doivent rester parcimonieux, mais ils ne doivent pas être plus simple que nécessaire. Pour que l'analyse de scénarios reste pertinente, il est important que les modèles macroéconomiques reproduisent les faits stylisés les plus importants. La prise en compte du changement structurel dans la demande de papier influence déjà les décisions d'investissement en faveur d'autres produits et services forestiers. Dans un avenir proche, la consommation de produits forestiers va continue d'évoluer, la prochaine frontière consistera à modéliser d'autres changements structurels à venir.

B. Appendix to chapter 3 additional samples

This document contains test results for two supplementary data sets mentioned in the article: a first panel dataset starts in 1961 and contains data for 12 countries (N) and over 53 years (T); a second panel starts in 1970 (N=14, T=44) and includes the largest country, i.e. Germany. Results for a third dataset are reported in the body of the article. For information, the third dataset starts in 1980 (N=15, T=34) and contains price and GDP series labelled in euros instead of us dollars.

B.1. Unit root tests

B.1.1. PANIC (2004)

Table B.1.: PANIC (2004) test of H_0 : non stationarity on data from 1961 to 2013

Product	Consumption		GDP		Price	
	Common	Idiosyncratic	Common	Idiosyncratic	Common	Idiosyncratic
Newsprint	2.19 I(1)	-0.15 I(1)	-1.22 I(1)	5.81 I(0)	4.63 I(0)	5.32 I(0)
PrintingandWritingPaper	-2.40 I(1)	-1.24 I(1)	-0.78 I(1)	5.00 I(0)	6.60 I(0)	1.41 I(1)
OtherPaperandPaperboard	6.13 I(0)	-2.63 I(1)	-1.22 I(1)	5.81 I(0)	8.94 I(0)	-0.42 I(1)
SawnwoodConiferous	2.34 I(1)	1.57 I(1)	-1.22 I(1)	5.81 I(0)	6.31 I(0)	6.09 I(0)
ParticleBoard	4.80 I(0)	-0.05 I(1)	-1.02 I(1)	6.51 I(0)	13.51 I(0)	6.26 I(0)
Fibreboard	2.63 I(1)	-0.43 I(1)	-0.98 I(1)	6.20 I(0)	17.22 I(0)	-0.34 I(1)

Note: Tests performed with a maximum of 4 lags. The PANIC pooled demeaned test has a critical value of 2.87 at the 5 percent level, a null hypothesis of homogeneous non-stationary is rejected above that value. The pooled idiosyncratic test has a critical value of 1.64 at the 5 percent level.

Table B.2.: PANIC (2004) test of H_0 : non stationarity on data from 1970 to 2013

Product	Consumption		GDP		Price	
	Common	Idiosyncratic	Common	Idiosyncratic	Common	Idiosyncratic
Newsprint	0.16 I(1)	1.45 I(1)	4.54 I(0)	7.11 I(0)	19.03 I(0)	3.33 I(0)
PrintingandWritingPaper	-1.11 I(1)	-1.49 I(1)	5.34 I(0)	7.10 I(0)	11.99 I(0)	2.57 I(0)
OtherPaperandPaperboard	6.04 I(0)	-2.03 I(1)	4.54 I(0)	7.11 I(0)	13.50 I(0)	0.66 I(1)
SawnwoodConiferous	5.42 I(0)	2.25 I(0)	4.54 I(0)	7.11 I(0)	11.51 I(0)	6.76 I(0)
ParticleBoard	2.70 I(1)	-0.92 I(1)	3.13 I(0)	7.39 I(0)	13.22 I(0)	2.97 I(0)
Fibreboard	5.37 I(0)	-0.80 I(1)	3.54 I(0)	7.13 I(0)	8.78 I(0)	1.68 I(0)

Note: Same comments as for the table above.

B.1.2. Carrion-i-Silvestre (2005)

Table B.3.: Llús Carrion-i-Silvestre et al. test of H_0 : stationarity on data from 1961 to 2013

Product	Consumption		GDP		Price	
	het	hom	het	hom	het	hom
Newsprint	I(1) 6.20 (0.00)	I(0) 1.13 (0.13)	I(1) 67.44 (0.00)	I(1) 24.56 (0.00)	I(1) 2.31 (0.01)	I(0) 1.64 (0.05)
PrintingandWritingPaper	I(1) 4.80 (0.00)	I(1) 4.64 (0.00)	I(1) 67.44 (0.00)	I(1) 24.56 (0.00)	I(1) 3.63 (0.00)	I(0) 1.07 (0.14)
OtherPaperandPaperboard	I(1) 7.19 (0.00)	I(1) 4.97 (0.00)	I(1) 70.75 (0.00)	I(1) 29.03 (0.00)	I(1) 3.53 (0.00)	I(0) 0.49 (0.31)
SawnwoodConiferous	I(1) 6.69 (0.00)	I(1) 2.26 (0.01)	I(1) 70.12 (0.00)	I(1) 24.81 (0.00)	I(1) 3.53 (0.00)	I(1) 3.32 (0.00)
ParticleBoard	I(1) 9.15 (0.00)	I(1) 4.73 (0.00)	I(1) 67.44 (0.00)	I(1) 24.56 (0.00)	I(1) 4.49 (0.00)	I(1) 2.88 (0.00)
Fibreboard	I(1) 3.58 (0.00)	I(0) 0.70 (0.24)	I(1) 67.44 (0.00)	I(1) 24.56 (0.00)	I(1) 9.36 (0.00)	I(1) 3.30 (0.00)

Notes: p values are indicated in parenthesis. A maximum of 5 structural changes allowed. N = 12, T = 53. Hom and het represent homogenous and heterogenous long-run variance.

Table B.4.: Llús Carrion-i-Silvestre et al. test of H_0 : stationarity on data from 1970 to 2013

Product	Consumption		GDP		Price	
	het	hom	het	hom	het	hom
Newsprint	I(1) 3.68 (0.00)	I(1) 14.17 (0.00)	I(1) 37.98 (0.00)	I(1) 21.01 (0.00)	I(0) 0.40 (0.35)	I(0) 0.17 (0.43)
PrintingandWritingPaper	I(1) 4.58 (0.00)	I(1) 11.30 (0.00)	I(1) 37.98 (0.00)	I(1) 21.01 (0.00)	I(0) 0.36 (0.36)	I(0) 0.71 (0.24)
OtherPaperandPaperboard	I(1) 6.69 (0.00)	I(1) 5.03 (0.00)	I(1) 38.46 (0.00)	I(1) 21.53 (0.00)	I(0) -0.14 (0.55)	I(0) -0.51 (0.70)
SawnwoodConiferous	I(1) 3.19 (0.00)	I(1) 7.53 (0.00)	I(1) 40.56 (0.00)	I(1) 24.37 (0.00)	I(0) 1.44 (0.08)	I(1) 1.65 (0.05)
ParticleBoard	I(1) 8.23 (0.00)	I(1) 5.96 (0.00)	I(1) 37.98 (0.00)	I(1) 21.01 (0.00)	I(1) 4.12 (0.00)	I(1) 3.36 (0.00)
Fibreboard	I(1) 3.92 (0.00)	I(1) 2.73 (0.00)	I(1) 37.98 (0.00)	I(1) 21.01 (0.00)	I(1) 1.71 (0.04)	I(0) 0.08 (0.47)

Notes: same comments as for the above table except that N=14 and T=44.

B.1.3. Bai Carrion (2009)

Table B.5.: Bai Carrion-i-Silvestre test result for the consumption variable

Product	x	model	Z	P_m	P	Z^*	P_m^*	P^*
Newsprint	lcons	1	-1.4231	0.351	36.8948			
	lcons	1	I(1)	I(1)	I(1)			
	lcons	2	-2.2194	2.2261	52.3572			
	lcons	2	I(0)	I(0)	I(0)			
	lcons	3	-1.4231	0.351	36.8948	-1.4231	0.351	36.8948
	lcons	3	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lcons	4	-1.5915	0.417	37.439	5.6439	-0.3097	31.4459
Printing and Writing Paper	lcons	4	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)
	lcons	1	-0.1312	-0.5467	27.6265			
	lcons	1	I(1)	I(1)	I(1)			
	lcons	2	1.6347	-1.7115	18.3079			
	lcons	2	I(1)	I(0)	I(1)			
	lcons	3	-0.1312	-0.5467	27.6265	-0.1312	-0.5467	27.6265
	lcons	3	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
Other Paper and Paperboard	lcons	4	-1.0948	1.3159	42.5271	0.5507	-1.11	23.1202
	lcons	4	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lcons	1	3.6458	-1.3605	26.1395			
	lcons	1	I(0)	I(1)	I(1)			
	lcons	2	0.1099	0.2324	40.0261			
	lcons	2	I(1)	I(1)	I(1)			
	lcons	3	3.6458	-1.3605	26.1395	3.6458	-1.3605	26.1395
Sawnwood Coniferous	lcons	3	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)
	lcons	4	-0.3321	1.5866	51.8313	-0.7059	1.1847	48.3281
	lcons	4	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lcons	1	-1.7459	2.9094	60.687			
	lcons	1	I(0)	I(0)	I(0)			
	lcons	2	-0.0759	-0.121	34.9733			
	lcons	2	I(1)	I(1)	I(1)			
Particle Board	lcons	3	-1.7459	2.9094	60.687	-1.7459	2.9094	60.687
	lcons	3	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
	lcons	4	-1.2125	4.128	71.0274	1.336	3.4942	65.6491
	lcons	4	I(1)	I(0)	I(0)	I(1)	I(0)	I(0)
	lcons	1	0.3941	-1.2061	22.3514			
	lcons	1	I(1)	I(1)	I(1)			
	lcons	2	0.1986	0.2882	34.3054			
Fibreboard	lcons	2	I(1)	I(1)	I(1)			
	lcons	3	0.3941	-1.2061	22.3514	0.3941	-1.2061	22.3514
	lcons	3	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lcons	4	1e-04	0.8222	38.5774	1.6172	0.4317	35.4536
	lcons	4	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lcons	1	-0.4481	0.1472	35.2137			
	lcons	1	I(1)	I(1)	I(1)			
Fibreboard	lcons	2	0.6014	-0.662	28.5413			
	lcons	2	I(1)	I(1)	I(1)			
	lcons	3	-0.4481	0.1472	35.2137	-0.4481	0.1472	35.2137
	lcons	3	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lcons	4	-1.7299	1.8993	49.6618	-1.3768	1.363	45.2392
	lcons	4	I(0)	I(0)	I(0)	I(1)	I(1)	I(1)

Table B.6.: Bai Carrion-i-Silvestre test result for the GDP variable

Product	x	model	Z	P_m	P	Z*	P_m^*	P^*
Newsprint	lgdpreur	1	-1.4513	0.0649	34.5348			
	lgdpreur	1	I(1)	I(1)	I(1)			
	lgdpreur	2	-0.2113	-0.1177	33.0294			
	lgdpreur	2	I(1)	I(1)	I(1)			
	lgdpreur	3	-1.4513	0.0649	34.5348	-1.4513	0.0649	34.5348
	lgdpreur	3	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lgdpreur	4	-0.5129	0.1396	35.1509	1.5633	-0.2635	31.8267
	lgdpreur	4	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
Printing and Writing Paper	lgdpreur	1	-1.1245	-0.5023	27.9813			
	lgdpreur	1	I(1)	I(1)	I(1)			
	lgdpreur	2	0.0205	-0.3715	29.028			
	lgdpreur	2	I(1)	I(1)	I(1)			
	lgdpreur	3	-1.1245	-0.5023	27.9813	-1.1245	-0.5023	27.9813
	lgdpreur	3	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lgdpreur	4	0.4545	-0.1488	30.8096	1.9088	-0.5846	27.3235
	lgdpreur	4	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)
Other Paper and Paperboard	lgdpreur	1	-2.262	1.4583	50.7129			
	lgdpreur	1	I(0)	I(1)	I(1)			
	lgdpreur	2	-1.6569	1.8037	53.7241			
	lgdpreur	2	I(0)	I(0)	I(0)			
	lgdpreur	3	-2.262	1.4583	50.7129	-2.262	1.4583	50.7129
	lgdpreur	3	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)
	lgdpreur	4	2.128	-1.9297	21.1775	2.5352	-1.4322	25.5142
	lgdpreur	4	I(0)	I(0)	I(1)	I(0)	I(1)	I(1)
Sawwood Coniferous	lgdpreur	1	-2.2955	1.3674	47.603			
	lgdpreur	1	I(0)	I(1)	I(1)			
	lgdpreur	2	-0.5565	0.5978	41.0726			
	lgdpreur	2	I(1)	I(1)	I(1)			
	lgdpreur	3	-2.2955	1.3674	47.603	-2.2955	1.3674	47.603
	lgdpreur	3	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)
	lgdpreur	4	1.8123	-0.3968	32.6333	4.6165	-0.9536	27.9086
	lgdpreur	4	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)
Particle Board	lgdpreur	1	-1.7586	-0.2349	30.121			
	lgdpreur	1	I(0)	I(1)	I(1)			
	lgdpreur	2	-0.6312	0.0362	32.29			
	lgdpreur	2	I(1)	I(1)	I(1)			
	lgdpreur	3	-1.7586	-0.2349	30.121	-1.7586	-0.2349	30.121
	lgdpreur	3	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)
	lgdpreur	4	0.0297	-0.0627	31.4987	1.3097	-1.0065	23.9478
	lgdpreur	4	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
Fibreboard	lgdpreur	1	-2.0726	1.0134	42.3567			
	lgdpreur	1	I(0)	I(1)	I(1)			
	lgdpreur	2	-0.982	0.7848	40.4715			
	lgdpreur	2	I(1)	I(1)	I(1)			
	lgdpreur	3	-2.0726	1.0134	42.3567	-2.0726	1.0134	42.3567
	lgdpreur	3	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)
	lgdpreur	4	0.1789	-0.6096	28.9735	6.9296	-0.8793	26.7488
	lgdpreur	4	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)

Table B.7.: Bai Carrion-i-Silvestre test result for the price variable

Product	x	model	Z	P_m	P	Z^*	P_m^*	P^*
Newsprint	lpricereur	1	-2.2611	3.1962	60.3569			
	lpricereur	1	I(0)	I(0)	I(0)			
	lpricereur	2	-2.8336	5.3707	78.288			
	lpricereur	2	I(0)	I(0)	I(0)			
	lpricereur	3	-2.2611	3.1962	60.3569	-2.2611	3.1962	60.3569
	lpricereur	3	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
	lpricereur	4	-2.8336	5.3707	78.288	-2.8336	5.3707	78.288
Printing and Writing Paper	lpricereur	4	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
	lpricereur	1	-1.5322	2.2107	49.6853			
	lpricereur	1	I(1)	I(0)	I(0)			
	lpricereur	2	-1.9917	3.5809	60.6472			
	lpricereur	2	I(0)	I(0)	I(0)			
	lpricereur	3	-1.5322	2.2107	49.6853	-1.5322	2.2107	49.6853
	lpricereur	3	I(1)	I(0)	I(0)	I(1)	I(0)	I(0)
Other Paper and Paperboard	lpricereur	4	-2.1823	3.32	58.5599	-2.2824	3.5324	60.2595
	lpricereur	4	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
	lpricereur	1	-1.9056	2.6541	61.1379			
	lpricereur	1	I(0)	I(0)	I(0)			
	lpricereur	2	-2.3096	5.1527	82.92			
	lpricereur	2	I(0)	I(0)	I(0)			
	lpricereur	3	-1.9056	2.6541	61.1379	-1.9056	2.6541	61.1379
Sawnwood Coniferous	lpricereur	3	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
	lpricereur	4	-2.6088	5.4302	85.339	-2.5901	4.6061	78.1548
	lpricereur	4	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
	lpricereur	1	-0.844	1.8096	51.3548			
	lpricereur	1	I(1)	I(0)	I(0)			
	lpricereur	2	-0.6199	0.8097	42.8701			
	lpricereur	2	I(1)	I(1)	I(1)			
Particle Board	lpricereur	3	-0.844	1.8096	51.3548	-0.844	1.8096	51.3548
	lpricereur	3	I(1)	I(0)	I(0)	I(1)	I(0)	I(0)
	lpricereur	4	-0.9642	1.5271	48.9578	-0.647	1.1032	45.3611
	lpricereur	4	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lpricereur	1	-0.74	1.4982	43.9853			
	lpricereur	1	I(1)	I(1)	I(1)			
	lpricereur	2	-2.3657	3.716	61.7276			
Fibreboard	lpricereur	2	I(0)	I(0)	I(0)			
	lpricereur	3	-0.74	1.4982	43.9853	-0.74	1.4982	43.9853
	lpricereur	3	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lpricereur	4	-1.9697	3.358	58.8637	-1.8284	3.3776	59.0207
	lpricereur	4	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
	lpricereur	1	0.1203	-0.6354	28.7602			
	lpricereur	1	I(1)	I(1)	I(1)			
Fibreboard	lpricereur	2	-1.8912	2.9533	58.3538			
	lpricereur	2	I(0)	I(0)	I(0)			
	lpricereur	3	0.1203	-0.6354	28.7602	0.1203	-0.6354	28.7602
	lpricereur	3	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	lpricereur	4	-1.8912	2.9533	58.3538	-1.8912	2.9533	58.3538
	lpricereur	4	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
	lpricereur	4	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)

B.2. Cointegration tests

B.2.1. Westerlund (2007)

Table B.8.: Westerlund (2007) test of H_0 : no cointegration between y , g and p

	Product	G_t	G_a	P_t	P_a
Constant	Newsprint	-2.58 (0.08)	-9.10 (0.49)	-8.67 (0.45)	-12.10 (0.26)
	PrintingandWritingPaper	-2.29 (0.31)	-8.89 (0.53)	-9.53 (0.14)	-13.51 (0.08)
	OtherPaperandPaperboard	-3.02 (0.00)	-17.09 (0.00)	-10.39 (0.33)	-19.26 (0.01)
	SawnwoodConiferous	-3.32 (0.00)	-13.19 (0.02)	-10.44 (0.00)	-10.60 (0.05)
	ParticleBoard	-2.84 (0.01)	-7.58 (0.41)	-10.24 (0.01)	-8.23 (0.05)
	Fibreboard	-1.88 (0.72)	-7.01 (0.74)	-9.09 (0.23)	-10.46 (0.20)
Constant and trend	Newsprint	-2.36 (0.90)	-7.11 (0.99)	-9.34 (0.80)	-13.04 (0.79)
	PrintingandWritingPaper	-2.38 (0.86)	-8.74 (0.98)	-9.31 (0.85)	-12.00 (0.88)
	OtherPaperandPaperboard	-3.28 (0.10)	-15.66 (0.43)	-12.80 (0.41)	-21.53 (0.22)
	SawnwoodConiferous	-3.21 (0.12)	-12.36 (0.69)	-10.94 (0.50)	-10.85 (0.77)
	ParticleBoard	-2.94 (0.31)	-8.06 (0.97)	-8.60 (0.47)	-8.55 (0.73)
	Fibreboard	-2.99 (0.23)	-11.07 (0.78)	-11.15 (0.47)	-12.75 (0.64)

Notes: bootstrap p-values are reported in parenthesis. 1 to 3 lags and leads chosen by AIC (Akaike Information Criterion). Data between 1961 and 1970, N = 12 and T = 53.

Table B.9.: Westerlund (2007) test of H_0 : no cointegration between y , g and p

	Product	G_t	G_a	P_t	P_a
Constant	Newsprint	-2.22 (0.51)	-6.57 (0.78)	-8.06 (0.35)	-7.77 (0.55)
	PrintingandWritingPaper	-2.08 (0.64)	-6.29 (0.86)	-10.93 (0.19)	-11.79 (0.23)
	OtherPaperandPaperboard	-2.75 (0.13)	-12.28 (0.09)	-12.90 (0.09)	-15.19 (0.09)
	SawnwoodConiferous	-2.99 (0.05)	-9.62 (0.25)	-11.44 (0.27)	-9.27 (0.38)
	ParticleBoard	-2.65 (0.07)	-7.77 (0.42)	-10.43 (0.03)	-9.96 (0.06)
	Fibreboard	-2.34 (0.39)	-5.06 (0.97)	-7.89 (0.48)	-6.65 (0.59)
Constant and trend	Newsprint	-2.35 (0.87)	-5.65 (1.00)	-8.45 (0.79)	-8.16 (0.94)
	PrintingandWritingPaper	-2.43 (0.95)	-7.60 (1.00)	-10.76 (0.56)	-11.50 (0.73)
	OtherPaperandPaperboard	-3.50 (0.12)	-12.10 (0.69)	-15.26 (0.22)	-16.64 (0.33)
	SawnwoodConiferous	-3.04 (0.38)	-8.53 (0.96)	-11.72 (0.57)	-9.61 (0.81)
	ParticleBoard	-3.27 (0.17)	-9.68 (0.82)	-11.45 (0.10)	-9.82 (0.64)
	Fibreboard	-3.02 (0.20)	-8.86 (0.72)	-8.83 (0.66)	-9.32 (0.68)

Notes: Same as above for data between 1970 and 2013, N = 14 and T = 44.

B.2.2. Westerlund and Edgerton (2007)**Table B.10.:** Westerlund and Edgerton (2007) test of H_0 : cointegration for the panel as a whole. Data from 1961 to 2013.

Product	Constant		Constant and Trend	
	LM_N^+	p -value	LM_N^+	p -value
Newsprint	2.32	1.00	8.87	0.38
PrintingandWritingPaper	1.44	1.00	8.35	0.11
OtherPaperandPaperboard	3.30	0.85	8.77	0.01
SawnwoodConiferous	1.58	1.00	5.50	0.71
ParticleBoard	8.42	0.56	10.97	0.05
Fibreboard	7.43	0.70	7.76	0.00

Notes: bootstrap p-values are reported. Tests are performed with a maximum of 3 lags ($N = 12$, $T = 53$)

Table B.11.: Westerlund and Edgerton (2007) test of H_0 : cointegration for the panel as a whole. Data from 1970 to 2013.

Product	Constant		Constant and Trend	
	LM_N^+	p -value	LM_N^+	p -value
Newsprint	3.59	0.92	10.94	0.03
PrintingandWritingPaper	NA	NA	9.65	0.28
OtherPaperandPaperboard	NA	NA	6.85	0.17
SawnwoodConiferous	1.96	1.00	5.96	0.52
ParticleBoard	NA	NA	9.24	0.00
Fibreboard	NA	NA	7.41	0.00

Notes: bootstrap p-values are reported. Tests are performed with a maximum of 3 lags ($N = 14$, $T = 44$)

B.2.3. Banerjee Carrion (2015)

Table B.12.: Banerjee Carrion-i-Silvestre test of H_0 : no cointegration. Data from 1980 to 2013.

Product \ Model	1	2	3	4	6	7
Newsprint	0.34	-1.223	1.485	-1.014	-0.294	0.59
Printing and Writing Paper	-1.349	-1.261	0.141	-0.209	-0.948	-1.051
Other Paper and Paperboard	-1.669	-2.504	-1.646	-1.71	-1.725	-1.542
Sawnwood Coniferous	0.524	-1.327	0.715	-1.614	-2.356	-2.774
Particle Board	-1.424	-3.127	0.741	-1.897	-1.436	-4.142
Fibreboard	-0.692	-1.062	0.15	-1.782	-0.887	-1.052

Notes: Test performed with one common factor. For models 1,3,6 with a constant and for T=50 periods, the 5% critical value Z_c^* is equal to -2.219. For models 2,4,7 with a trend, the 5% critical value $Z_r^* = -2.120$. Variables below the critical values are highlighted in bold.

- 1- individual effects model (Pedroni model),
- 2- individual and time effects model (Pedroni model),
- 3- individual effects and one level shift model (no break in the cointegrating vector),
- 4- individual and time effects and one level shift (no break in the cointegrating vector),
- 6- individual effects, with both level and cointegrating vector shift,
- 7- individual and time effects, with both level (no trend shift) and cointegrating vector shift

Table B.13.: Banerjee Carrion-i-Silvestre test of H_0 : no cointegration. Data from 1961 to 2013.

Product \ Model	1	2	3	4	6	7
Newsprint	-1.287	-1.771	0.559	-1.757	-0.674	-0.052
Printing and Writing Paper	-3.498	-2.804	-1.671	-1.211	-1.381	-0.746
Other Paper and Paperboard	-2.546	-2.515	-2.133	-3.147	-1.970	-2.951
Sawnwood Coniferous	-2.345	-1.460	-3.189	-1.107	-3.385	-1.457
Particle Board	-0.374	0.236	0.000	0.616	-1.477	-1.631
Fibreboard	-3.307	-4.729	-1.125	-4.896	-0.071	-2.262

Notes: See previous table

Table B.14.: Banerjee Carrion-i-Silvestre test of H_0 : no cointegration. Data from 1970 to 2013.

Product \ Model	1	2	3	4	6	7
Newsprint	-0.086	-0.019	1.040	0.328	-1.405	0.490
Printing and Writing Paper	-2.796	-0.627	-1.155	-0.313	-0.320	-0.412
Other Paper and Paperboard	-4.782	-6.680	-2.423	-6.467	-3.565	-4.000
Sawnwood Coniferous	-0.892	-1.370	-0.507	-3.545	-1.666	-4.079
Particle Board	-2.187	-2.339	-1.599	-1.827	-1.179	-0.957
Fibreboard	-1.160	-1.117	-1.734	-0.967	-1.510	-1.236

Notes: See previous table

B.3. Demand elasticities

B.3.1. Estimation by DOLS and PMG

Table B.15.: Demand elasticities estimated by the DOLS and PMG methods - on data from 1961 to 2013

Product	DOLS		PMG	
	GDP	Price	GDP	Price
Newsprint	0.625 (0.0407)	-0.0266 (0.0578)	0.25 (0.02)	-0.25 (0.13)
PrintingandWritingPaper	0.845 (0.0508)	0.316 (0.0903)	0.56 (0.03)	-0.17 (0.14)
OtherPaperandPaperboard	0.712 (0.0497)	-0.526 (0.0797)	0.43 (0.02)	-0.34 (0.09)
SawnwoodConiferous	0.528 (0.0365)	-0.087 (0.052)	0.07 (0.01)	-0.22 (0.07)
ParticleBoard	0.806 (0.0809)	-0.56 (0.088)	0.40 (0.07)	-0.21 (0.18)
Fibreboard	0.601 (0.094)	-0.668 (0.0965)	0.77 (0.09)	-0.58 (0.20)

Notes: DOLS estimations performed with one lag and one lead. Standard errors in parenthesis.(N = 12, T = 53)

Table B.16.: Demand elasticities estimated by the DOLS and PMG methods - on data from 1970 to 2013

Product	DOLS		PMG	
	GDP	Price	lgdprusd	lprice
Newsprint	0.949 (0.057)	-0.0675 (0.0671)	0.45 (0.04)	-0.20 (0.10)
PrintingandWritingPaper	1.04 (0.0549)	0.127 (0.081)	0.40 (0.04)	-0.42 (0.14)
OtherPaperandPaperboard	0.966 (0.0415)	-0.292 (0.0575)	0.16 (0.02)	-0.29 (0.08)
SawnwoodConiferous	0.91 (0.0405)	0.0101 (0.051)	0.07 (0.02)	-0.25 (0.06)
ParticleBoard	0.866 (0.0518)	-0.186 (0.0738)	0.42 (0.05)	0.13 (0.10)
Fibreboard	0.751 (0.0984)	-0.541 (0.107)	0.92 (0.10)	-0.59 (0.18)

Notes: DOLS estimations performed with one lag and one lead. Standard errors in parenthesis.(N = 14, T = 44)

B.3.2. Comparison plot

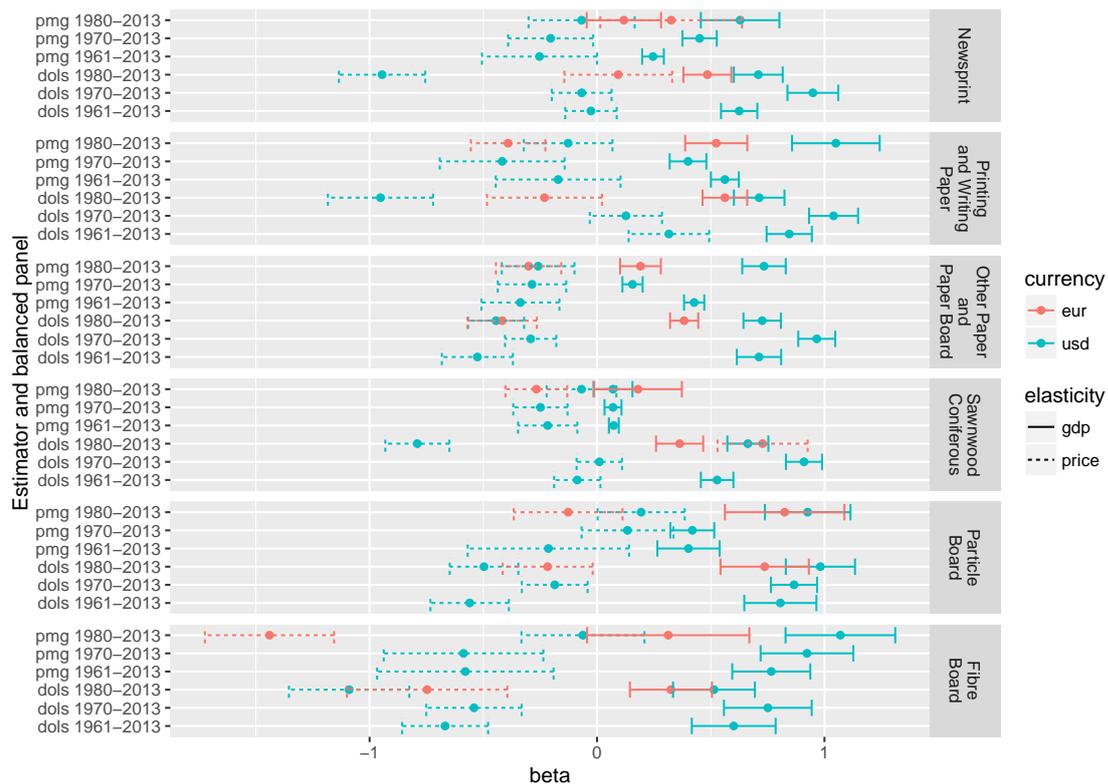


Figure B.1.: Comparison of demand elasticities (bars indicate 2 times the standard error) between 3 balanced panels: $(N=12, T=53)$, $(N=14, T=44)$ and $(N=15, T=34)$. The last panel has data both in constant Euros and constant Dollars.

B.4. GFPM demand scenarios

B.4.1. Comparison of estimated elasticities with the literature

Estimation Product	Buongiorno2015		DOLS		PMG		Simangunsong2001	
	gdp	price	gdp	price	gdp	price	gpd	price
Newsprint	0.39	-0.04	0.48	0.02	0.13	0.22	1.02	-0.54
PrintingandWritingPaper	0.59	-0.53	0.56	-0.28	0.49	-0.41	1.30	-0.38
OtherPaperandPaperboard	0.40	-0.45	0.38	-0.44	0.21	-0.30	1.13	-0.30
SawnwoodConiferous	0.24	-0.17	0.36	0.66	0.21	-0.37	0.78	-0.35
ParticleBoard	0.59	-0.51	0.73	-0.25	0.99	-0.18	1.02	-0.14
Fibreboard	0.92	-0.54	0.32	-0.76	0.39	-1.42	1.38	-0.26

Table B.17.: Elasticities estimated by DOLS and PMG panel cointegration methods compared to elasticities from the GFPM base scenario (Buongiorno 2015) and the average of the literature review by Simangunsong (2001).

B.4 GFPM demand scenarios

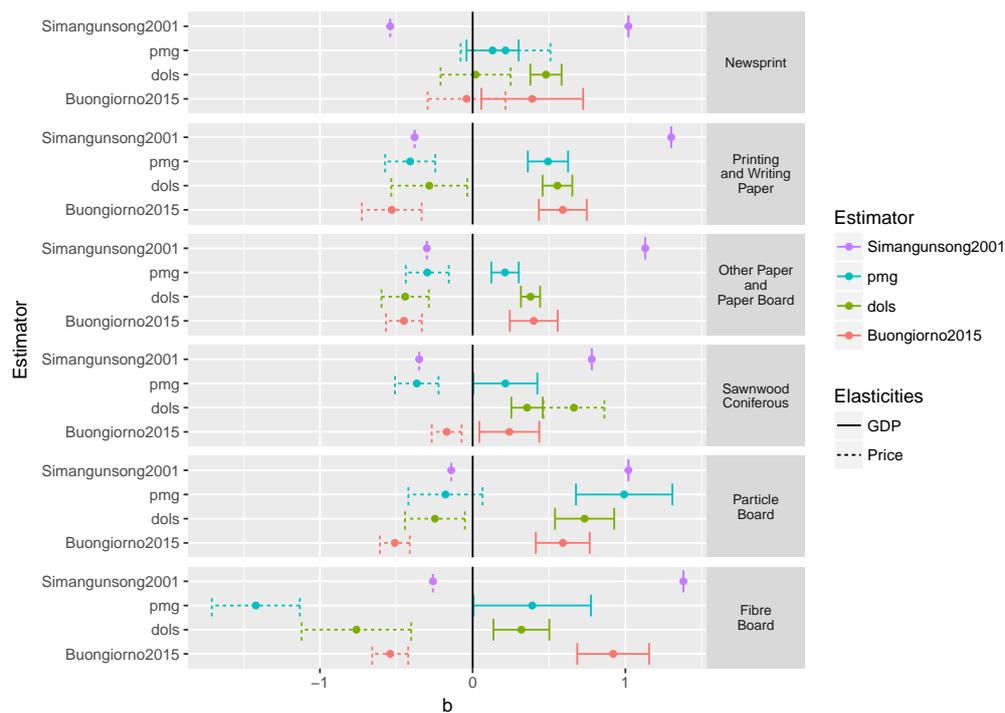


Figure B.2.: Comparison of demand elasticities between the various scenarios (bars indicate 2 times the standard error when available)

B.4.2. GFPM demand scenarios

Product	DOLS	PMG	Buongiorno2015
Newsprint	-43%	-46%	-42%
PrintingandWritingPaper	-32%	-33%	-31%
OtherPaperandPaperboard	-24%	-26%	-24%
Sawnwood	-26%	-27%	-23%
ParticleBoard	-17%	-17%	-16%
Fibreboard	-19%	-20%	-17%

Table B.18.: Changes in world prices from the GFPM simulation for the products of interest

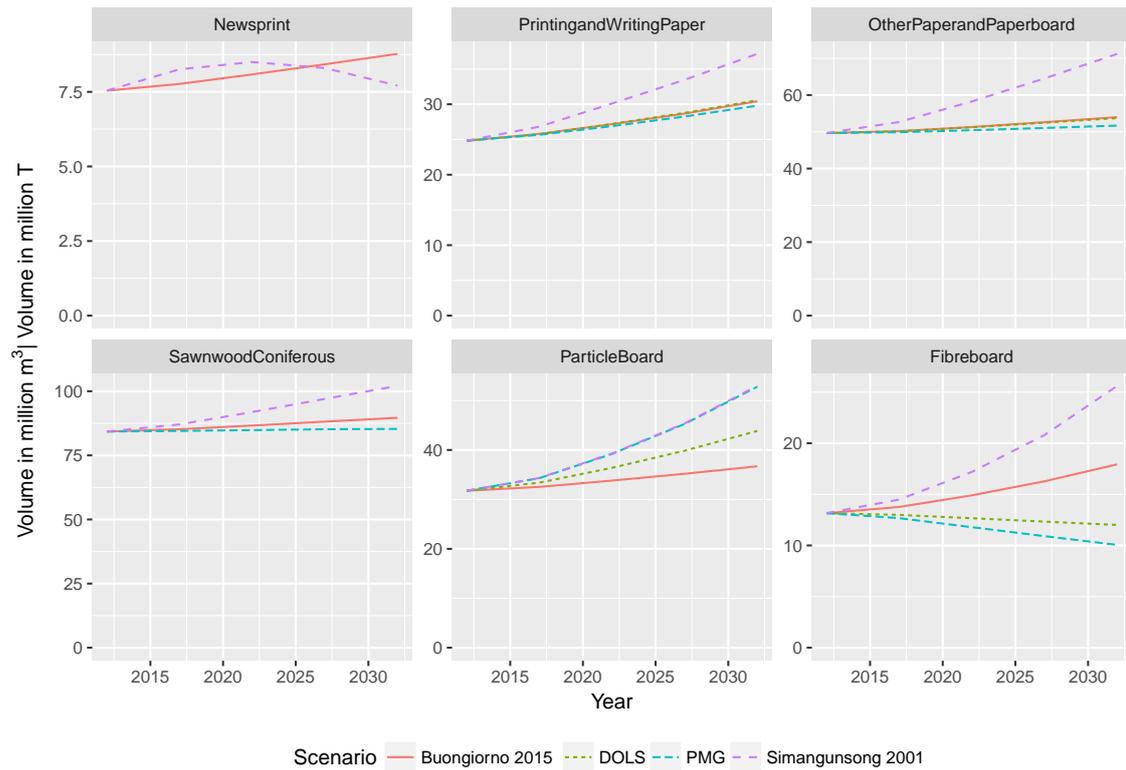


Figure B.3.: GFPM demand scenarios for Europe, base year 2012

C. Appendix to chapter 4

C.1. Panel cointegration tests

Table C.1.: Panel cointegration test results Banerjee and Carrion-i-Silvestre (2015)

Product	1	2	3	4	6	7
Newsprint	-1.543	0.041	0.354	2.242	-0.048	-0.898
PrintingandWritingPaper	-0.945	-0.794	-1.250	-2.305	-1.988	0.402
OtherPaperandPaperboard	-1.722	-2.053	0.820	-1.742	1.029	0.094

Note: The 5% critical values for this test are $Z_c = -2.219$ for models with a constant and $Z_\tau = -2.120$ for models with a trend.

¹ individual effects model (Pedroni model),

² individual and time effects model (Pedroni model),

³ individual effects and one level shift model (no break in the cointegrating vector),

⁴ individual and time effects and one level shift (no break in the cointegrating vector),

⁶ individual effects, with both level and cointegrating vector shift,

⁷ individual and time effects, with both level (no trend shift) and cointegrating vector shift

C.2. Thresholds results for consumption per capita in difference

Table C.2.: Panel threshold test results

Product	Threshold 1	P-value	Threshold 2	P-value
Newsprint	0.520	0.003	0.413	0.027
Printing and Writing Paper	0.282	0.360	0.538	0.040
Other Paper and Paperboard	0.032	0.083	0.011	0.076

Note: Critical values are the outcome of 300 bootstrap replications.

Table C.3.: Panel threshold regression on difference(consumption per capita)

Product	Threshold	Variable	Coeff	Std Err	T-Stat	Signif
Newsprint	internet < 52%	gdpcd	1.152	0.375	3.08	0.002
		priced	0.615	0.258	2.38	0.018
	internet > 52%	gdpcd	-0.002	0.003	-0.73	0.465
		priced	0.011	0.006	2.03	0.043
Printing and Writing Paper	internet < 28%	gdpcd	0.719	0.390	1.84	0.066
		priced	4.420	1.006	4.39	0.000
	53%>internet > 28%	gdpcd	0.611	0.255	2.40	0.017
		priced	-0.002	0.003	-0.69	0.493
internet > 53%	gdpcd	-0.004	0.010	-0.44	0.660	
	priced	0.011	0.006	2.07	0.039	

Note: variable gdpcd is the first difference of GDP per capita. variable priced is the first difference of prices.

C.3. DOLS and PMG estimation before and after an average break

Table C.4.: DOLS estimation before and after an average break date

Item	1980-2000		2001-2015		2006-2015	
	GDP	Price	GDP	Price	GDP	Price
Newsprint	0.92 (0.088)	-0.437 (0.0939)	0.963 (0.173)	-0.749 (0.207)	1.02 (0.296)	-0.901 (0.252)
Printing and Writing Paper	1.18 (0.103)	-0.108 (0.119)	1.13 (0.161)	-0.227 (0.262)	1.18 (0.288)	0.0624 (0.297)
Other Paper and Paper Board	0.997 (0.0763)	-0.335 (0.0936)	1.15 (0.169)	-1.09 (0.119)	1.17 (0.221)	-0.937 (0.116)

Note: DOLS estimates performed with one lag and one lead.

Table C.5.: PMG estimation before and after an average break date

Item	1980-2000		2001-2015		2006-2015	
	GDP	Price	GDP	Price	GDP	Price
Newsprint	0.89 (0.04)	-0.1 (0.06)	-1.03 (0.11)	0.49 (0.13)	-0.57 (0.10)	1.2 (0.11)
PrintingandWritingPaper	1.13 (0.03)	-0.09 (0.03)	0.95 (0.12)	0.51 (0.31)	1.22 (0.32)	-1.72 (0.40)
OtherPaperandPaperboard	0.46 (0.04)	0.1 (0.07)	0.4 (0.05)	0.04 (0.06)	0.79 (0.06)	0.01 (0.03)

Note: Standard errors in parenthesis.

C.4. Descriptive statistics

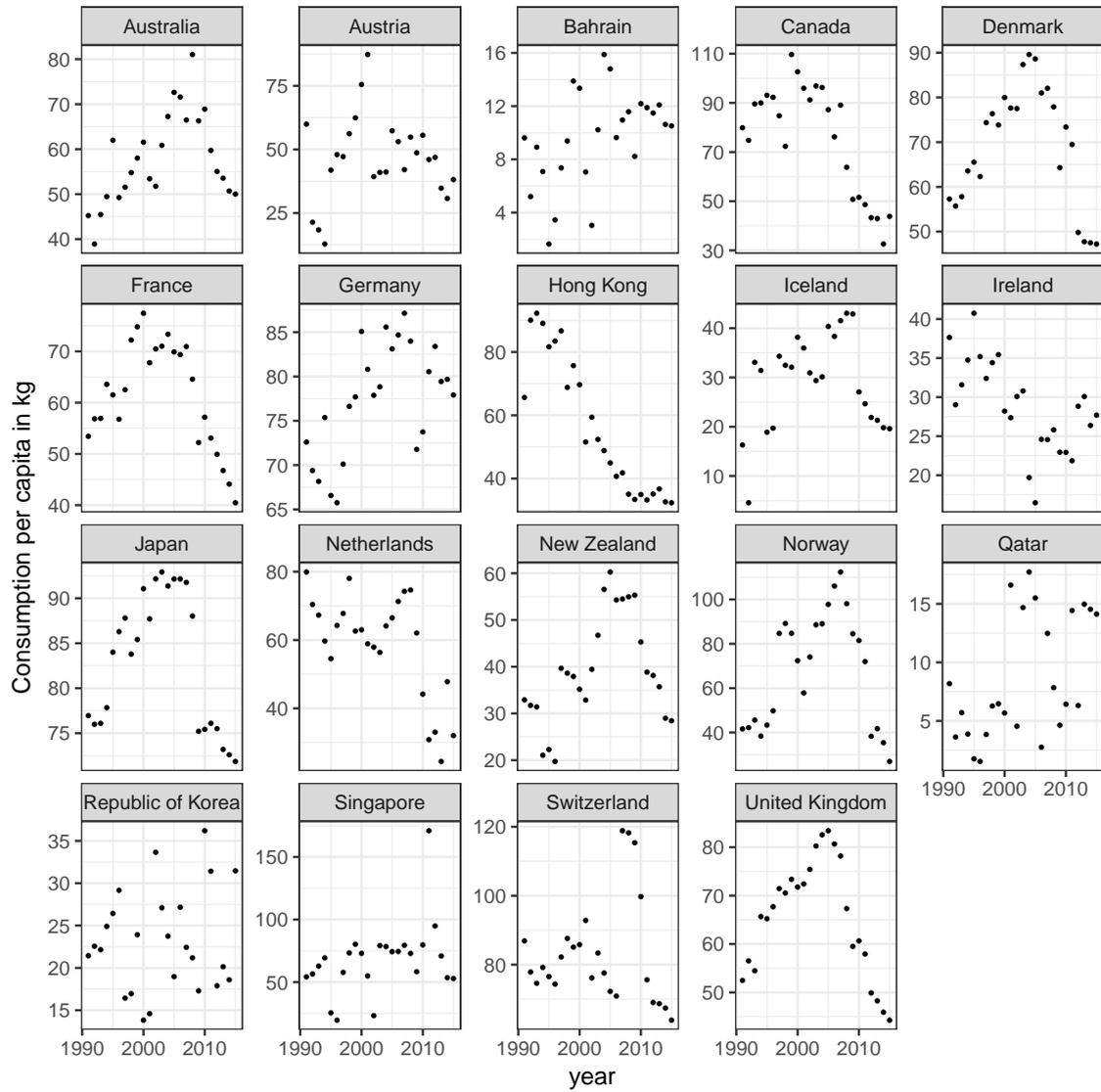


Figure C.1.: Printing and writing paper consumption in advanced internet countries

Table C.6.: Evolution of internet penetration rate and paper consumption

Countries reaching 80% penetration rate			Total consumption in million m^3		
Year	Country name	Count	Newsprint	Printing and Writing Paper	Other Paper and Paper Board
1990		0	12	28	46
1991		0	12	29	48
1992		0	12	29	48
1993		0	12	29	48
1994		0	13	31	51
1995		0	14	32	52
1996		0	13	32	53
1997		0	14	33	54
1998		0	14	33	52
1999		0	14	36	54
2000		0	15	36	57
2001		0	15	35	57
2002		0	15	36	56
2003	Iceland	1	14	37	57
2004	Sweden, Denmark	3	14	38	57
2005	Netherlands, Norway	5	15	37	58
2006		5	15	37	59
2007	Finland	6	15	38	60
2008	Republic of Korea	7	14	36	58
	United Kingdom,				
2009	Canada, Switzerland	10	12	31	54
2010	Germany, New Zealand	12	12	32	58
2011		12	12	32	57
2012	France, Austria, Bahrain	15	11	30	58
	Japan, Australia,				
2013	Singapore, Qatar	19	10	29	58
2014		18	10	28	59
2015	Hong Kong, Ireland	21	9	28	58

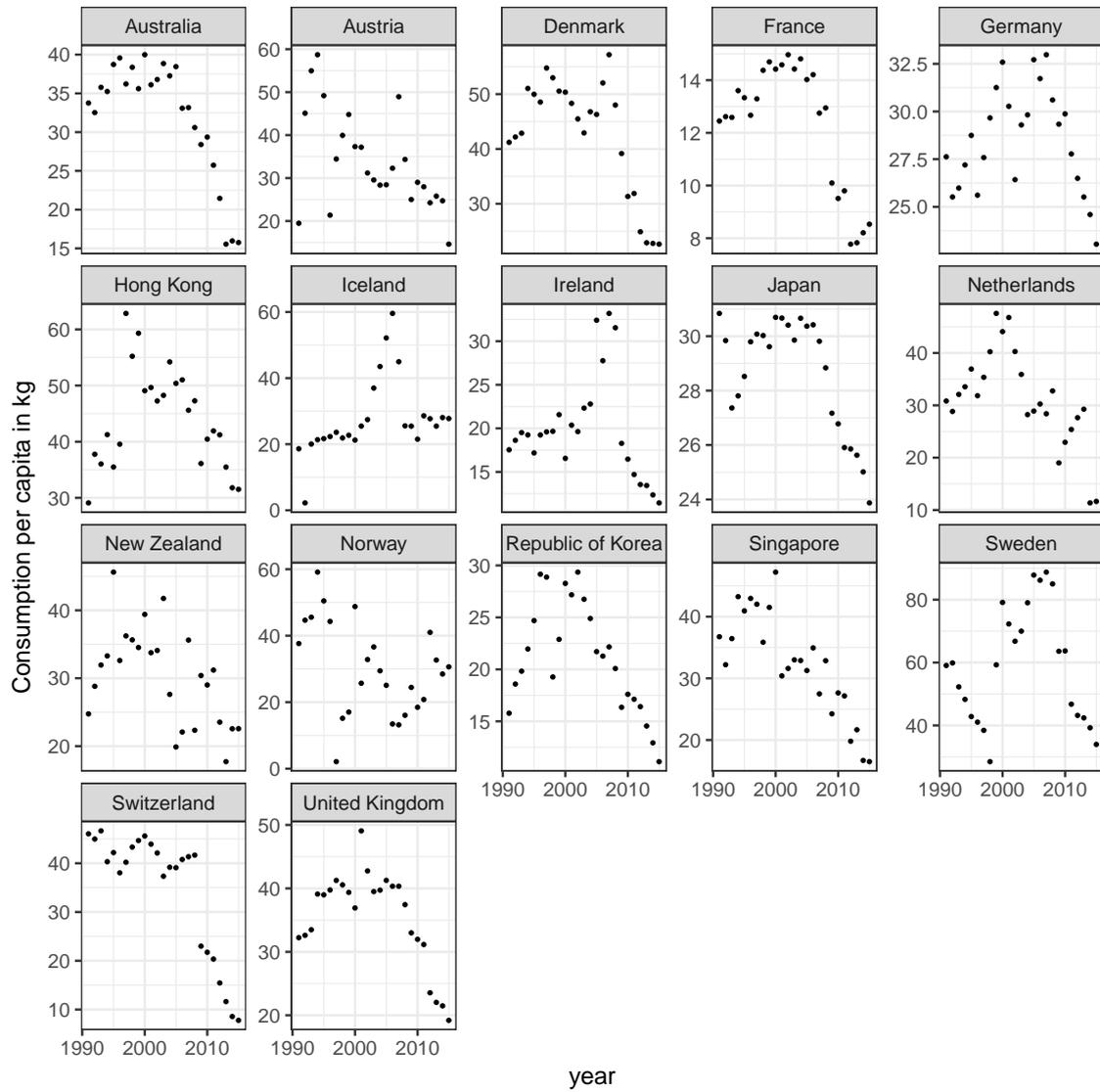


Figure C.2.: Newsprint consumption in advanced internet countries

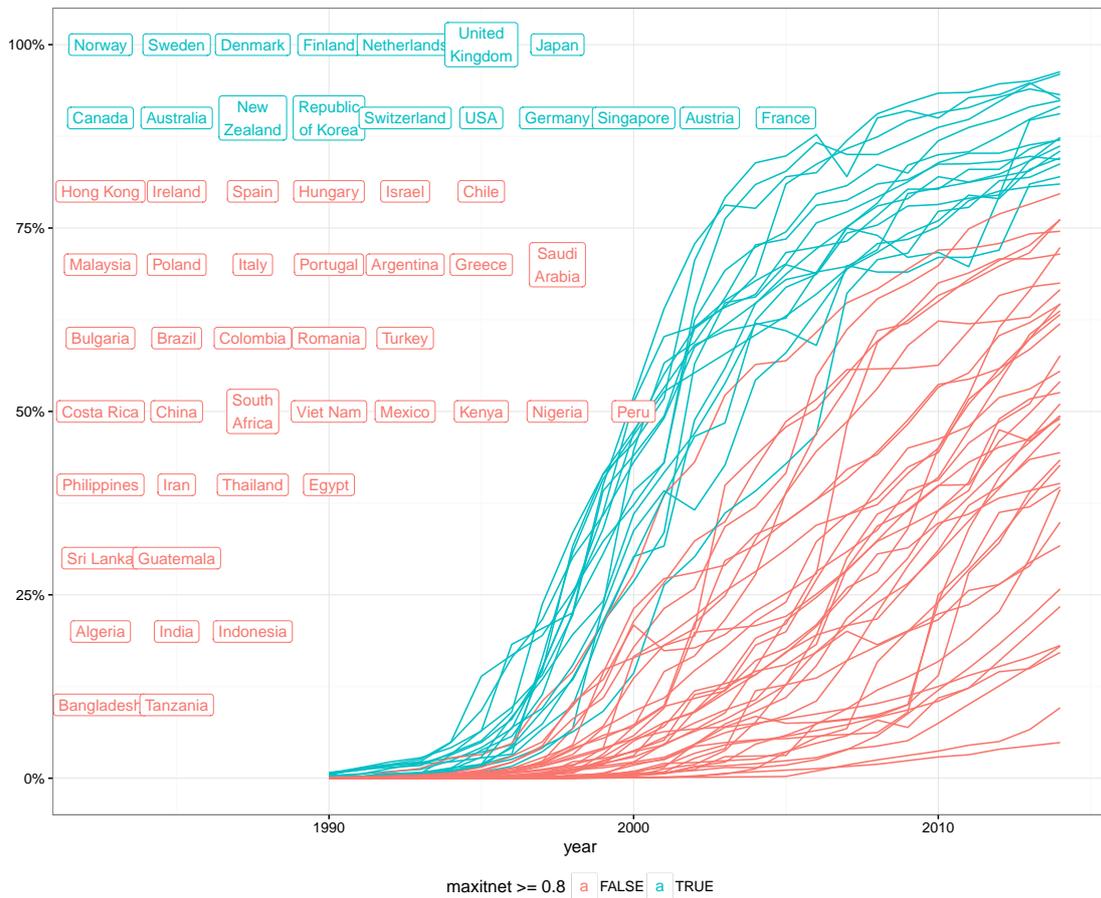


Figure C.3.: Percentage of internet users in the 50 largest paper consuming countries

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Nomenclature

AFOLU	Agriculture, Forestry and Other Land Uses
EFI-GTM	European Forest Institute Global Trade Model
EU	European Union
FAOSTAT	The Statistics Division of the Food and Agriculture Organization of the United Nations
FASOM	Forest and Agricultural Sector Optimization Model
FFSM	French Forest Sector Model
FSC	Forest Stewardship Council
FSM	Forest Sector Model
GFPM	Global Forest Products Model
IPCC	Intergovernmental Panel on Climate Change
PEFC	Programme for the Endorsement of Forest Certification
SF-GTM	Model of the Finnish Forest Sector