Econometric Analysis of global wood markets and its implications on international forest products modelling

Dissertation

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Table of content

List of Tables V

List of Figures VII

Summary VIII

Zusammenfassung X

1. General Introduction 1

1.1. Aim of this thesis 2

1.2. Changing market patterns in wood markets 3

1.3. Econometrics for the forest sector 4

1.4. Forest sector modelling 5

1.5. Structure of this thesis 6

1.5.1. Supply and demand functions for global wood markets 6

1.5.2. Emerging lignocellulose-base products 7

1.5.3. The Structural Gravity Model 8

1.6. References 10

2. Supply and Demand Functions for global wood markets: Specification and plausibility testing of econometric models within the global forest sector 14

2.1. Abstract 15

2.2. Introduction 16

2.3. Methodology and Data 17

2.3.1. Methodology 17

2.3.2. Supply functions: Theoretical framework 21

2.3.3. Demand functions: Theoretical framework 22

2.3.4. Data 22

2.4. Results 24

2.4.1. Supply in domestic and international markets: 24

2.4.1.1. Wood removals from planted or natural forests: 26

2.4.1.2. Industrial roundwood: 27

2.4.1.3. Fuelwood: 28

2.4.2. *Demand in domestic and international markets:* *28*

2.4.2.1. *Sawnwood* *29*

2.4.2.2. *Plywood and Veneer sheets:* *30*

2.5. *Plausibility Testing* *30*

2.6. *Discussion and Conclusion* *33*

2.7. *References* *36*

2.8. *Appendix* *40*

3. *Estimating supply and demand elasticities of dissolving pulp, lignocellulose-based chemical derivatives and textile fibres in an emerging forest-based bioeconomy* *45*

3.1. *Abstract* *46*

3.2. *Introduction* *47*

3.3. *Methods* *49*

3.3.1. *Products and Data* *50*

3.3.1.1. *Products* *50*

3.3.1.2. *Data Sources* *51*

3.3.1.3. *Panel Data* *52*

3.3.1.4. *Input Data Constancy and Time Series Cuts* *53*

3.3.2. *Econometric Model Specification and Testing* *54*

3.3.2.1. *Econometric Panel Data Models* *54*

3.3.2.2. *Statistical diagnostic test for model specification* *56*

3.3.2.3. *Testing the substitutability of regression coefficient estimates* *57*

3.4. *Results and Discussion* *58*

3.4.1. *Input data constancy and time series cuts* *58*

3.4.2. *Statistical Diagnostic for Model Specification* *62*

3.4.3. *Elasticity coefficient estimates* *63*

3.4.4. *Testing for equality of elasticity coefficient estimates* *67*

3.5. *Conclusion* *69*

3.6. *References* *72*

3.7. *Annex* *77*

3.7.1. *Input Data Clearing* *77*

3.8. Tables and Figures 78

4. Modelling Bioeconomy Scenario Pathways for the Forest Products Markets with Emerging Lignocellulosic Products 91

4.1. Abstract 92

4.2. Introduction 93

4.3. Materials and Methods 94

4.3.1. GFPM 95

4.3.2. Implementation of Lignocellulose-Based Products in the GFPM Framework 96

4.3.3. Future Pathways for Bioeconomy Scenarios 98

4.4. Results 99

4.5. Discussion 102

4.6. Conclusions 106

4.7. Appendix 108

4.8. References 111

5. The structural gravity model and its implications on global forest product trade 115

5.1. Abstract 116

5.2. Introduction 117

5.3. Materials and Methods 118

5.3.1. Methodology 118

5.3.2. Data 121

5.4. Results and Discussion 124

5.4.1. Industrial Roundwood 126

5.4.2. Sawnwood 127

5.4.3. Veneer, Plywood and Fibreboard 127

5.4.4. Wood pulp, Newsprint and Paper & Paperboards 127

5.5. Conclusion 129

5.6. Appendix 131

5.7. References 139

6. Discussion and Conclusion 142

6.1. Research questions and key findings 143

6.2. Discussion of methods 147

6.3. Conclusion and Outlook 149

6.4. References 152

Authorship contribution XII

Acknowledgments XVI

Curriculum Vitae XVII

List of Tables

Chapter 2

Table 2.1 Industrial Roundwood removals (in 1000 m³) by country in 2012 23

Table 2.2 Price elasticities of supply for roundwood products 25

Table 2.3 Price elasticities of exports for selected roundwood products 26

Table 2.4 Price Elasticities of domestic supply for selected roundwood products 26

Table 2.5 Price elasticities of demand 28

Table 2.6 Price elasticities of imports 29

Table 2.7 Validation of the modified GFPM 33

Table 2.8 Forest area in different regions 40

Table 2.9 Industrial Roundwood removals (in 1000 m³) by country in 2012 41

Table 2.10 Detailed results obtained for the price elasticities of domestic supply for three different time series and two different income groups for selected roundwood products 43

Table 2.11 Detailed results obtained for the price elasticities of domestic demand for three different time series and two different income groups for plywood and sawnwood products 44

Chapter 3

Table 3.1 Results from parameter constancy tests with OLS-based MOSUM (H0: parameter constancy) 60

Table 3.2 Results from the econometric estimations of income and price elasticities from macroeconomic panel data models for different periods and products 64

Table 3.3 Results from testing the statistical equality of regression coefficients for dissolving pulp import demand and net domestic consumption for different time periods (H0: no statistical difference) 68

Table 3.4 Decoding of commodity aggregates cellulose chemical derivatives and textile fibres for the present study 78

Table 3.5 Results showing the significant influence of sub periods in an aggregated model estimation with gdp, price, and dummy variable for the periods 79

Table 3.6 Summary of main characteristics from 28 panel data sets employed for econometric model estimations 79
Table 3.7 Results from econometric model specification and misspecification tests statistics 80
Table 3.8 Dissolving pulp income and price elasticity estimations 81
Table 3.9 Cellulose-based chemical derivatives income and price elasticity estimations 85
Table 3. 10 Cellulose-based textile fibres income and price elasticity estimations 88

Chapter 4

Table 4.1 Assumptions on future forest sector developments (displayed as global averages). 98
Table 4.2 Scenario results from the simulation of three alternative bioeconomy scenarios. 100
Table 4.3 Selection of country specific information about Cellulose-based textile fibers (TF). 108
Table 4.4 Dissolving pulp (DP) input for the production of lignocellulose-based textile fibers (TF) as a result of the linear optimization procedure for the year 2015. 109
Table 4.5 Assumptions on future forest sector developments for the top ten producers of industrial roundwood (displayed as country specific averages). 110

Chapter 5

Table 5.1 Determinants of global wood market trade 122
Table 5. 2 Estimation results for the product group 'forest products' 125
Table 5.3 Comparison of GDP effects from structural (own estimations) and traditional gravity (results from [12,13]) 129
Table 5.4 Total variable selection 133
Table 5.5 Estimation results for the product group 'industrial roundwood' 135
Table 5.6 Estimation results for the product group 'sawnwood' 136
Table 5.7 Estimation results for the product group 'veneer, plywood and fibreboard' 137
Table 5. 8 Estimation results for the product group 'wood pulp, newsprint and paper & paperboard' 138

List of Figures

Chapter 2

Figure 2.1 Production structure in original GFPM 19

Figure 2.2 Results obtained with the modified GFPM and re-estimated econometric parameters in 1000 m³ 31

Figure 2.3 Original GFPM results in 1000 m³ 32

Chapter 3

Figure 3.1 Shifting demand pattern in wood products markets from Western to Eastern markets 47

Figure 3.2 Global export supply and import demand of dissolving pulp, cellulose based textile fibres, and chemical derivatives.* 61

Figure 3.3 Inspection of residuals from dissolving pulp regression models against explanatory variable "price" to check for reverse causality problem due to endogeneity 90

Chapter 4

Figure 4.1 Suggested Model Structure and Transformation Processes in the GFPM. Note: Ind. Round. = Industrial Roundwood 95

Figure 4.2 Scheme of production data generation for lignocellulose-based chemical derivatives and textile fibres 97

Figure 4.3 Paper pulp and dissolving pulp production globally. 103

Figure 4.4 Change in the global market shares of a specific product between 2015 and 2050, by product 105

Summary

Global economic systems are changing due to several possible influences, like globalization, climate change, or social transformation. Even though, the wood markets analysis is well established and developed for many kinds of applications economic models remain simplified descriptions of reality and must, therefore, adapt to changing market patterns. This PhD thesis aims to improve forest sector analysis by enhancing economic modelling approaches of international forest products markets. The focus is on implementing actual econometric findings in economic models. To achieve this objective three steps were undertaken in this thesis.

First, the existing analysis about supply and demand functions in wood markets were actualized with modern econometric methods as existing literature often concentrate on dependencies in isolated aspects of wood market, while the interactions with other aspects were ignored. To close this gap in research, the way in which the amount of wood supplied, demanded, and traded affects market equilibria was analyzed econometrically in this thesis. In this context, the supply side of a partial economic equilibrium model was extended by differing between roundwood from planted and from natural forests. The modified model shall depict the growing importance of wood from planted forests. After the extension take place, the model was supplemented with the results of the newly established econometric models. This procedure mainly serves to check the plausibility of estimated elasticities. However, the performance of the improved model also serves to validate the extension of the economic model. One main result of this part is that price and income elasticities in demand behave as predicted by economic theory, while price elasticities of both imports as well as exports are significantly negative. These results can be interpreted in a way that the trade of wood commodities is driven by demand in international markets.

Second, until now little attention has been paid to macroeconomic relationships of lignocellulosic products. Hence, economic models often do not account for this sub-sector. To close this gap in research the present thesis implements dissolving pulp, lignocellulosic chemical derivatives, and textile fibres within the context of a partial equilibrium model. In preparation for this, market elasticities were estimated by using econometric panel data models. As the next step, a partial economic equilibrium model was extended by a lignocellulose-based sub-sector. This methodological enhancement is, until now, unique and makes it possible to model and analyze the interdependencies that may occur between traditional and emerging forest-based sectors. Eventually, the modified model was used to simulate scenarios about possible transitions from a petrol-based economy to a sustainable bio-based economy. Our findings suggest that, if the world could change toward a sustainable bioeconomy, consumption of roundwood could shift towards more efficient production of wood-based panels or lignocellulose-based materials. However, such developments must be accompanied with technological changes to reduce the total amount of wood input in the final products. This would generate additional resources potentials for new wood-based products.

Third, existing econometric literature in bilateral trade flows of wood markets concentrate on the traditional definition of the gravity model of trade. However, these models cannot account for sectoral or product-specific effects and therefore leave a gap in the analysis of wood market trade. To close this gap different structural definitions of gravity was developed in economics. Until now these models were not used in wood market analysis. This dissertation aims to close this gap by introducing a structural framework of gravity to wood markets. The use of such framework will open the possibility to include effects on sectoral or product level and additionally, gives a broad economic background which offers new intersections to future wood market modelling approaches.

Zusammenfassung

Durch die Globalisierung, den Klimawandel oder den sozialen Wandel befinden sich Märkte auf der ganzen Welt im Umbruch. Holzmärkte bilden hier keine Ausnahme. Die Analyse dieser ist mit zahlreichen Anwendungsmöglichkeiten gut etabliert. Dennoch kann die ökonomische Modellierung immer nur eine Abbildung der Realität darstellen, welche auf gravierende Veränderungen der Rahmenbedingungen angepasst werden muss. Diese Dissertation hat zum Ziel die Analyse von Holzmärkten zu verbessern, indem die bisherige Modellierung dieser Märkte erweitert wird. Der Fokus wird hierbei auf die Implementierung ökonometrischer Analysen in die Modellierung von partiellen Gleichgewichtsmodellen gelegt. Um das Ziel dieser Dissertation zu erreichen, wird in drei Phasen vorgegangen.

Erstens, bereits existierende Schätzungen zu Preiselastizitäten von Angebot und Nachfrage auf internationalen Holzmärkten werden mithilfe moderner ökonometrischer Methoden aktualisiert. Dies wird notwendig, da die existierende Literatur sich bisher vorwiegend auf isolierte Aspekte der Märkte konzentriert hat und das Zusammenwirken dieser meist ignoriert wurden. Um diese Lücke zu schließen, wird in dieser Dissertation analysiert wie das Angebot, die Nachfrage und der Handel das Gleichgewicht internationaler Holzmärkte beeinflussen. In diesem Zusammenhang wird das Angebot nach Rundholz in einem partiellen ökonomischen Gleichgewichtsmodells um die Herkunft aus gepflanzten oder Naturwäldern erweitert. Dies soll die wachsende Bedeutung von Holz aus angepflanzten Wäldern auf globaler Ebene widerspiegeln. Die aktualisierten Schätzergebnisse zu Elastizitäten globaler Holzmärkte werden in das erweiterte partielle Gleichgewichtsmodell eingebettet. Diese Prozedur dient hauptsächlich der Plausibilisierung der Schätzergebnisse, allerdings könnte durch den Vergleich mit dem originalen Modell auch Schlussfolgerungen zur Validität der Modellerweiterungen getroffen werden. Eines der Hauptergebnisse dieser Phase ist, dass das inländische Angebot von Holzprodukten kaum auf Preisänderungen reagiert, während das Angebot im internationalen Handel negativ mit Preisänderungen korreliert. Zusammen mit den signifikant negativen Reaktionen der Nachfrage nach Holzprodukten auf Preisänderungen liegt die Schlussfolgerung nahe, dass Holzmärkte auf globaler Ebene von der Nachfrage dominiert werden.

Zweitens, Lignocellulose-basierten Produkten wird bis heute in der makroökonomischen Analyse kaum Bedeutung beigemessen. Dementsprechend werden diese Produkte auch in der Holzmarktmodellierung selten beachtet, auch wenn diese in Zukunft eine wichtige Rolle einnehmen könnten. Um diese Lücke zu schließen, wird in dieser Arbeit ein Sub-Sektor für Lignocellulose basierte Produkte in ein partielles Gleichgewichtsmodell integriert. Hierfür wird das Modell zunächst um diesen Sub-Sektor erweitert und dann mit den hierfür notwendigen Preiselastizitäten für Angebot und Nachfrage dieser Produkte versehen. Letztere werden dafür mithilfe ökonometrischer Methoden in Panels ermittelt. Diese Herangehensweise ist bis

heute einzigartig und macht es möglich das Zusammenwirken zwischen diesem aufkommenden neuen Sub-Sektor und den traditionellen Holzmärkten aufzuzeigen. Das so entstandene erweiterte Gleichgewichtsmodell für internationale Holzmärkte wird dann genutzt, um unterschiedliche Transformationspfade von der heutigen Rohöl-basierten Volkswirtschaft zu einer Bioökonomie zu simulieren. Ein Ergebnis dieser Phase ist, dass eine umfassende Transformation zur Bioökonomie dazu führt, dass Rundholz verstärkt für die Herstellung von Produkten, wie z.B. Platten und Lignocellulose-basierte Produkte, verwendet werden könnte. Allerdings sollte die Transformation von technologischem Fortschritt begleitet werden, da dies den Materialinput in den Herstellungsprozessen verringern würde und so das freiwerdende Potential an Holz für diese aufstrebenden Produkte verwendet werden könnte.

Drittens, die bestehende ökonometrische Literatur zu bilateralem Handel im internationalen Holzmarkt verlässt sich bisher auf die traditionelle Definition von Gravitationsmodellen internationalen Handels. Diese Modelle ignorieren allerdings zumeist sektor- und produktspezifische Effekte im Holzhandel. Um diese Lücke zu schließen, wurden strukturelle Gravitationsmodelle entwickelt, welche bisher noch nicht für die Holzmarktanalyse verwendet wurden. In dieser Dissertation wird eine strukturelle Definition des Gravitationsmodells für den globalen Holzmarkt eingeführt. Mithilfe verschiedener ökonometrischer Modelle können damit Zusammenhänge auf internationalen Holzmärkten in einen Detailgrad aufgezeigt werden, welches bisher nicht möglich war. Diese Definition erklärt zudem bilateralen Holzhandel mit einem erweiterten theoretischen Hintergrund und eröffnet damit bisher unbekannte Schnittpunkte zur Holzmarktmodellierung.

Give me a fruitful error any time, full of seeds, bursting with its own corrections. You can keep your sterile truth for yourself.

Vilfredo Pareto

1. General Introduction

Global economic systems underwent several progressive developments in the past due to social transformation, globalization, and climate change. The academic research and model-based analysis of economic systems must anticipate and cope with such market changes because outdated models may not be effective anymore. This is also true for wood markets.

The analysis of wood markets already started with Johann Heinrich von Thünen in 1842 and is, until now, well established and developed using several economic methods. Nevertheless, economic models are only simplified descriptions of reality. Therefore, the wood market modelling must adapt to changing market patterns to maintain the ability to understand these markets. If such developments are ignored, modelling procedures may become biased in future. One way to bind models to reality is the econometric analysis, where economic data are analyzed to determine and quantify the relationship between a dependent variable and one or more independent variables. Such statistical analysis of economic data can be implemented in economic modelling processes to improve or update these models. However, even if improvement of modelling procedures is always desirable, these updates may also influence the model's behavior and must be implemented cautiously.

1.1. Aim of this thesis

This PhD thesis aims to improve forest sector analysis by enhancing economic modelling approaches of international forest products markets. The focus is on implementing actual econometric findings in economic models to achieve this objective. This work is guided by exploring and answering the following key questions:

1. How do supply, demand, and trade behave in international forest products markets, and what do estimated elasticities tell us about these markets?
2. How do wood market models respond to changes in market patterns?
3. Which are the underlying mechanisms for bilateral trade in wood markets?

The improvement and update of an economic modelling process via econometric analysis could not be done in just one step. At least for this thesis, I suggest an implementation procedure of four steps. The first is to identify changes in market patterns. This will mark the starting point, for the second step, the econometric analysis. The third step is to implement the results from the second step into economic models, and the fourth step is to validate the new or updated model. If the model does not run smoothly, a fifth step may be advisable: changing other model parameters to get the model run. However, if just one of these four steps is left out the whole process may become biased. For example, if the first step is ignored, the econometric analysis may not cover the essential variables, resulting in an incomplete model.

On the other hand, if the model is not validated after the change, the model may not work anymore in an intended way.

1.2. Changing market patterns in wood markets

As said above, one of the first steps to enhancing economic modelling approaches is to identify changes in market patterns. Therefore, this sub-chapter aims to describe some of the main causes that may influence the development of patterns in forest product markets, like social transformation, technological progress, and developments in markets itself.

Social transformation "*… implies an underlying notion of the way society and culture change in response to such factors as economic growth, war, or political upheavals*." (p. 15, Castles, 2001). This complex process changes the behavior and priorities of societies. For wood markets, the growing international ecological awareness may be of special interest because this transformation will influence the production of raw wood as well as the consumption of manufactured wood products and give advantages to market participants who already apply to the "new" focus. Sooner or later society will influence politics to design laws that may redefine the framework of market patterns in a more ecological and sustainable way. In this context, societies in the future may prefer a bio-based economy over the current fossil-based one which would have a big influence on wood markets. Also, the growing international ecological awareness could increase the need for more sustainable roundwood production and efficient wood products. The latter marks an interface between social transformation and technological progress because technological progress is a driver of social transformation itself. However, technological progress also determines the efficiency of manufacturing processes and, therefore, influences the costs of production of a specific product. Decreasing costs will influence the prices and behavior of the supply of markets. In the end, also the behavior of the demand side of markets will be influenced by technological progress by changing the budget constraints of these parts of markets. On the other hand, technology also defines the way in which scientific analysis can be carried out. Modern computers allow more complicated mathematical calculations which is the foundation for new modelling processes. For economic modelling, this is as important as the technological development in markets. Some modelling processes could only be thought of because of the upcoming modern information technology. Therefore, technological progress for economic models is not just a variable that should be modeled it is also something that defines the modelling process itself.

Another point which influences the development of markets, and thus the economic modelling process, are markets itself. Such development occurs because economic systems are driven by profit optimization. A good example of such development is globalization. Trade is not a transformation process of society itself; it is also not technological progress, but trade can be seen as a result of profit maximization. It can be said that the driver of globalization is trading, but globalization could not have occurred if the technology for transport had not existed. Therefore, globalization may be the best example to show the interdependencies of all three presented reasons for developments in markets: Globalization began with trade which is an influence driven by economic reasons. If technologies develop further, it allows trade to go farther around the world, for example, through new transport or packaging technics. In the end, globalization became a self-enforcing process that had even transformed societies worldwide. Nowadays, in the complex network of international relationships, trade plays a vital role in economic development, wealth, and intercultural exchange.

1.3. Econometrics for the forest sector

One classic approach in econometric analysis of wood markets is estimating the relationship between a dependent variable and one or more independent variables via Ordinary Least Squares (OLS). OLS is a technique to estimate this relationship by minimizing the sum of the squared residuals. This method can be applied in data sets with the cross country and for time series data. It is also possible to calculate the OLS in the panel, which combines individual and time series data. The combination of both dimensions introduces individual-specific effects which do not vary across time. These effects are called unobserved heterogeneity and can lead to inefficient and biased OLS estimators. One example of these effects is the age of an individual, as the difference in ages between individuals will always be the same throughout all time periods in a panel. To avoid unobserved heterogeneity there exists linear regression methods like fixed effects or random effects estimators (Wooldrigde, 2010). While fixed effect models (FE) try to explain heterogeneity across country levels by addressing it into individual specific constants, random effects methods (RE) assume the heterogeneity varies randomly across country levels. For the application of both models there exist different approaches. RE models for example can be estimated via Feasible General Least Squares (FGLS) (Greene, 2007). To estimate FE models methods like the within estimator, the least square dummy variable estimator (LSDV), or a first-difference model (FD) are available. Here the Within Estimator and the LSDV Estimator differ in the theoretical approach, but practically give the same results (Baltagi, 2008). However, as all these methods will be applied it is always challenging to choose the best model for a specific data set. For this purpose, testing approaches for the existence of unobserved heterogeneity (e.g., Breusch and Pagan, 1979), for the existence of non-stationarity (e.g., Maddala and Wu, 1999) or to determine whether unobserved effects were country-specific (e.g., Hausman, 1978) are essential. Especially for the econometric analysis of market elasticities, the three described regression models, OLS, FE, and RE, build the foundation of this PhD thesis.

Nevertheless, these models cannot be applied in every econometric approach. The analysis of bilateral trade, for example, cannot simply be solved by applying OLS, FE and RE estimations, because bilateral trade data split the individual country dimension in two: the importing and the exporting country. With these two dimensions on country level, the probability to find individual heterogeneity in the data increases and OLS and RE models would be biased by this kind of heterogeneity. Another point to consider is that models used to describe bilateral trade, like the gravity model, appear to be nonlinear. Therefore, linear models must be transformed in its log-log form. This would also be valid for the application of the FE model, but if heteroscedasticity is still persistent within the FE framework the estimation of such a framework becomes biased. To tackle problems like this, the use of the Poisson pseudo maximum likelihood estimator (PPML) is suggested (Silva and Tenreyro, 2006). The PPML estimation is one approach that works with these nonlinear problems and, when it comes to the estimation of bilateral trade relationships within an econometric model, to deal with non-existence or zero trade between a certain pair of countries. Especially the latter issue cannot be solved by using the log-log form of FE models (Benedictis and Taglioni, 2011).

1.4. Forest sector modelling

For the simulation of interdependencies in global wood markets, elasticities are used to define market reactions for demand and supply. Models built within partial equilibrium frameworks depend mainly on these input specifications (Romer, 2012). However, the estimation of market elasticities underly several uncertainties. Therefore, estimated elasticities should be tested on plausibility before relying on them within an economic modelling approach. To pursue such a validation approach, the estimated elasticities could be implemented in an existing economic simulation model. In literature, there are several models which fit such a procedure. Some examples are the Global Forest Trade Model (GFTM, Jonsson et al., 2015), the European Forest Institute-Global Trade Model (EFI-GTM, Kallio et al., 2004) or the Global Forest Product Model (GFPM, Buongiorno et. al 2003): “The GFPM is designed mainly as a policy analysis tool, to project the general future trends in quantities and prices at different stages of transformation, under different scenarios. “ (Buongiorno et al., 2003, p 39). For the purpose of this thesis, the GFPM was chosen to test the estimation results due to its open-source character and its structure which is based on FAOSTAT data, which is also the main data source for econometric analysis.

The Global Forest Products Model (GFPM) is a spatial dynamic economic equilibrium model designed to assess alternative forest sector developments under shifting market patterns, impacts of forest sector policies, or alternative forest management scenarios (Buongiorno et al. 2014; Johnston and Buongiorno 2017;

Van Kooten and Johnston 2014). The model links wood product supply, manufacturing, consumption, and trade (Buongiorno 2014; Turner et al. 2007). It simulates production, consumption, and trade volumes at the national to global level for 180 countries and 14 raw-, intermediate- and "end" products[1] in competitive world markets (Buongiorno 2003; Buongiorno et al. 2014). The input data for this model specification come from FAO forestry statistics (FAO 2020), the FAO Forest Global Resources Assessment (FRA, FAO 2015), and the World Bank (World Bank 2020). The FAOSTAT provides global and country wise data for the production and trade of forest products, while the FRA reports data for forest area and stock changes.

However, in its base structure the GFPM does not contain all commodities for which an econometric analysis for global wood markets would be possible. Therefore, for this PHD thesis the GFPM had been extended to implement some new commodities. After this procedure, the estimated elasticities, and the GDP development, as an exogenous parameter, were embedded in the model.

1.5. Structure of this thesis

The present thesis is structured into three main chapters. The first chapter deals with actualizing the existing analysis of supply and demand functions for traditional wood markets on a global scale with modern econometric methods and implementing these econometric models in an economic partial equilibrium model to analyze the implications of changing market patterns on international forest product markets (see section 1.5.1). Within the second chapter, supply and demand for emerging lignocellulose-based products were econometrically analyzed for the first time before the results were also be implemented in an economic partial equilibrium framework to analyze the resulting interdependencies with traditional forest product markets (see section 1.5.2). In the third chapter existing econometric modelling approaches of bilateral trade flows was improved by introducing the structural gravity model in forest product markets (see section 1.5.3).

1.5.1.Supply and demand functions for global wood markets

Planted forests were responsible for about 45 % of the global roundwood production in 2015 (FAO, 2015 and Jürgensen et al. 2014). Between 1990 and 2015, the global area of planted forests increased by about 64%, while the global forest area decreased by about 3% (FAO, 2015). These figures show that the production of roundwood from planted forests became increasingly a relevant factor in the supply of wood. Nevertheless, until now little is known about the behavior markets for wood from different origins on

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[1] Last stage of manufacturing covered by the GFPM. This does not refer to end-product markets like construction, furniture, or the textile sector as the GFPM, in its present form, is only able to calculate semi-finished products.

markets. Therefore, the present thesis aims to achieve knowledge about market patterns of roundwood to be able to extend the supply side of forest product markets models by differing between production of roundwood from planted and from natural forests. However, the equilibrium of wood markets is determined by interdependencies between supply, demand and trade. Shifts in supply will cause changes in the amount of wood consumed and traded. Vice versa, changes in other aspects of wood markets can as well cause changes in supply. Existing econometric studies often concentrate on dependencies in isolated aspects of wood market, e.g., Turner et al. (2006) analyze the effect of prices on supply, Michinaka et al. (2011) estimate determinants on the demand side of global wood markets, and Turner and Buongiorno (2004) concentrate on relationships in import. Even though the level of details can increase within isolated analyses, the interactions with other aspects of markets were ignored. To close this gap in research this thesis econometrically analyze the way in which the amount of wood supplied, demanded and traded together affect market equilibria in forest product markets. Eventually, the supply side of the GFPM was extended with roundwood from planted and from natural forests. This modified GFPM was supplemented with the results of the econometric models. This procedure serves to check the plausibility of estimated elasticities. However, the performances of the modified model also show if the extensions of the model work. To measure the performance of the modified model, the original GFPM version is used as a benchmark. Both models were started every year between 1992 and 2012 for nine periods each. The main driver for the simulations was the development of real GDP.

1.5.2.Emerging lignocellulose-base products

Social transformation changes the behavior and priorities of societies. Today, the shift from a petroleum-based to a more bio-based and sustainable industry marks one transformation process and is a response to demands from an increasingly ecologically conscious society and in order to cope with climate change. Especially for wood markets this transformation process may become more and more important in future as among the bio-based resources, biomass from wood is both an abundant and a very versatile raw material (Moohan et al. 2019). Wood serves to satisfy many needs of daily life, e.g., as a fuel for power and heating, or as input for the construction, furniture, paperboard, textile, and chemical industries. This lets the forest-based sector play diverse roles in a growing bioeconomy (Anderson et al. 1986).

Wood markets are already adapting to transformation processes: proceeding digitalization decreases the demand for graphic papers while the packaging industry is growing due to increasing online shop sales (FAO, 2020). Wood-based panel production catches up to sawn wood production (FAO 2020), and niche products like lignocellulosic textile fibres or chemical derivatives gain more and more importance as substitutes for petro-based products (Mohanty et al. 2018). The climate change debate and associated consequences propel the demand for sustainable forest products (Purkus and Lüdtke 2020). Considering the growing economic importance of lignocellulosic products, their inclusion in wood products market modelling seems to be important to analyze raw material allocation and intra-sectoral developments adequately. This product group is based on dissolved lignocellulose (dissolving pulp) whose global production is increasing from 3.42 million tons to 8.37 million tons between 2008 and 2018 which equals an annual increase of approximately 9% (FAO, 2020). Dissolving pulp is a raw material to produce cellulose-based chemical derivatives and regenerates. Cellulose-based chemical derivatives are used, e.g., in cellulose plastic materials and lacquers, whereas cellulose regenerates are mainly used for man-made fibre production (FAO, 2019; Bajpai, 2009).

However, until now little attention has been paid to macroeconomic relationships of these materials as, e.g., the investigation of market elasticities. Hence, economic models often do not account for this sub-sector because key economic parameters such as demand or supply elasticities of lignocellulose-based products are not available. To close this gap in research the present thesis implements dissolving pulp, lignocellulosic chemical derivatives, and textile fibres within the context of a partial equilibrium model. In preparation for this, market elasticities were estimated by using econometric panel data models. Since global production data of lignocellulosic chemical derivatives and textile fibres are not available on a freely accessible basis (but needed for partial equilibrium modelling), missing data about the production of these goods were filled with a linear programming approach uniquely designed for the purpose of this work. The GFPM was then extended by a lignocellulose-based sub-sector. This methodological enhancement is, until now, unique and makes it possible to model and analyze the interdependencies that may occur between traditional and emerging forest-based sectors. After these steps are done, the modified model is used to simulate scenarios about possible transitions from a petrol-based economy to a sustainable bio-based economy.

1.5.3.The Structural Gravity Model

Trade plays an important role for economic development, wealth, and intercultural exchange. Therefore, trade in the forestry and wood-based sector has already been analyzed in many ways, e.g., in context of the forest transition (Kastner et al. 2011), illegal logging (Li et al. 2008; Guan and Xu 2018) or the network theory (Lovrić et al. 2018). Trade is influenced by several different factors like income, free trade agreements (Buongiorno 2015), or shifting demand patterns (Johnston and van Kooten 2016). A theory that explains trade as whole is not within reach. However, in 1962, Tinbergen introduced the gravity model of trade to explain international trade on the macro level (Tinbergen 1962). This idea based on a basic principle of physics, where the mass of an object causes a force of attraction which diminishes with increasing distance; this force is called gravity. In economics a similar behavior can be observed: the economic mass of two partner countries attracts trade while the distance between them acts as a factor that reduces trade activities.

Until now, the gravity model of trade became mainstream in economics and is characterized by a long history across disciplines and by high empirical relevance (De Benedictis and Taglioni 2011). Existing studies for gravity in wood markets generally used only the GDP as proxy for economic mass, which is usually positively related, and the distance, which is usually negatively related to trade. This “traditional” definition of the gravity model refers to Tinbergen, in 1962, or Anderson, in 1979. Nevertheless, as this definition does only account for aggregated and not for sectoral or product specific trade, analysis in the forest sector might be a problematic because trade patterns differ across products. The GDP as aggregated income, for example, may be a good proxy in aggregated trade analysis but if included in analysis for the forest sector it may contain aggregation bias (Anderson and Yotov 2010; 2012), if sector specific effects were ignored. Existing literature does not account for this effect and leave a gap in the analysis of forest sector specific trade which the traditional gravity definition cannot close. This thesis aims to close this gap by introducing a structural definition of gravity to wood market analysis. This definition starts to explain trade as a part of the total expenditures of an economy and ended up, through several steps of transformation, with five main categories of variables that influence bilateral trade: gross production of traded goods in exporting country, apparent consumption in the importing country, an index of market potential, the degree of competition in that market, and bilateral accessibility. In practice, GDP is often used as a proxy for gross production and apparent consumption (Head and Mayer 2014). However, for the applications in wood markets the sectoral and product-specific production in the exporting country, as well as the sectoral and product-specific consumption in the importing country, may also offer a good fit for these kinds of variables. Bilateral accessibility in this framework refers to time-invariant characteristics of a country pair such as distance or language. The variables of market potential and degree of competition are hard to measure, even within this framework, however, the sectoral specific apparent consumption in the exporting country and the sectoral specific gross production in the importing country may be two parameters that fit into this gravity model of trade.

In sum, this structural framework explains bilateral trade on the sectoral or product level and additionally gives a broad economic background (Anderson and Yotov 2010; 2012; Head and Mayer 2014). Another advantage of the structural gravity model is that contrary to the traditional definition, intersections to wood market modelling approaches became possible in the future, as consumption and production are usually part of partial equilibrium models.

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2. Supply and Demand Functions for global wood markets: Specification and plausibility testing of econometric models within the global forest sector

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2.1. Abstract

Forests cover about one-third of the land surface on Earth. Currently, less than 7.5% of this forest area is defined as planted forest. Removals from planted forests are shown to be responsible for about 45 % of the global industrial roundwood production. It is therefore of great importance how the production of roundwood from planted forests will develop further and how this might impact the supply from natural forests and wood markets in general. The objective of this study was to specify global wood markets and implement wood removals from different types of forests, such as planted or natural. For this purpose, we use an econometric approach to analyze how global markets affect the amount of wood supply, demand and trade. As a result, in supply, only planted forest removals respond significantly positively to changes in price. The supply in all other products seems to be nearly inelastic. In demand every product shows significantly negative response to price changes. To test the plausibility of estimations, we implemented the obtained elasticities in an economic partial equilibrium model. The results suggest that the nearly inelastic wood supply improves model simulations as these were closer to historical data. The modified model will now be used for possible future developments of the areas natural and planted.

2.2. Introduction

Forests cover about one-third of the land surface on earth. Less than 7.5% of the forest area is planted forest, which is defined as "… predominantly composed of trees established through planting and/or deliberate seeding." (FAO, 2015). However, planted forests are responsible for about 45 % of the global roundwood production (FAO, 2015 and Jürgensen et al. 2014). Planted forests have developed dynamically over the last decades. Since 1990, the area of planted forests increased about 64%, while the global forest area decreased about 3% (FAO, 2015). During the same period, the global demand for industrial roundwood increased by about 37% (consumption of industrial roundwood by FAO, 2017). Since the production of roundwood from planted forests is a relevant factor in the supply of wood, it is necessary to attain knowledge about the relationships between the quantity of roundwood harvested from planted forests, on the one hand, and the economic factors influencing it, on the other hand.

At present, there are only few studies which discuss market interactions of wood removals from planted forests. Carle and Holmgren (2008) provide a detailed outlook for the potential area and volume of planted forests using surveys and a deterministic model. Cubbage et al. (2014) estimate investment returns for timber plantation species via dynamic investment appraisal methods. Buongiorno and Zhu (2014) use a partial equilibrium model to discuss effects of shifts in wood supply caused by changes in planted forests. The present study follows this field of investigation and aims to provide further knowledge about economic effects on the quantity harvested from planted forests. However, markets were always determined by interdependencies between supply, demand and trade. Thus, the other objective of the present study is to determine global wood market functions, while simultanously characterizing the market behavior of roundwood harvested from planted and natural forests. To achieve this objective, an econometric approach is used to analyze the way in which market equilibria affect the amount of wood supplied, demanded and traded. Existing literature, explicitly covering all aspects of wood markets are rare. Two exceptions are Kangas and Baudin (2003) dealing with market analysis in European countries, or McKillop (1983), aiming at the improvement of global trade modeling. However, none of these studies consider different forest types for timber production. In contrast to the above mentioned and the present study, existing econometric studies, which base on a similar methodology, often concentrate on dependencies in partial aspects of wood markets, e.g., Turner et al. (2006) analyze the effect of prices on supply; Michinaka et al. (2011) estimate determinants on the demand side of global wood markets, and Turner and Buongiorno (2004) concentrate on relationships in imports. Even though the level of detail can increase within such isolated analyses, the interactions with other aspects of markets cannot fully be taken into account. The present study addresses the latter issue by considering possible market interactions. With this comprehensive approach we intend to enhance the plausibility of econometric estimation results with reference to supply, demand and trade elasticities. To prove the plausibility of econometric estimations we use a global economic partial equilibrium model which uses market elasticities to calculate the interactions between all segments of the wood market.

The study is organized as follows: First, data and methods are explained. Thereafter, the results are tested and validated using a global economic partial equilibrium model. Finally, a discussion and conclusion summarizes this study.

2.3. Methodology and Data

2.3.1. Methodology

A simple but frequently approved way to analyze wood markets is to estimate the relationship between quantities and prices via Ordinary Least Squares (OLS). This method can be applied in cross country, time series or panel data. For global wood markets, data for the individual country level as well as time series information can be obtained. In such a panel, information about observed variables could vary across time or country level. This effect, called unobserved heterogeneity, can lead to inefficient and biased OLS estimators. Different methods can be used to avoid unobserved heterogeneity, e.g., Fixed Effects or Random Effects (Wooldridge, 2010).

Fixed Effect Models (FE) try to explain heterogeneity across country levels by addressing individual specific constants. In general, there are several approaches to estimating Fixed Effects, e.g.: The Within Estimator, the Least Square Dummy Variable Estimator (LSDV), or a First-Difference Model (FD). The Within Estimator and the LSDV Estimator differ in the theoretical approach but give practically the same results (Baltagi, 2008).

Equations (1) and (2) describe the Within Estimator and the First-Difference Model, with y as dependent and x as independent variables, β as coefficient and e as error term which covers minor influences. The vector which covers the individual data scale is illustrated with i, the time series in the data with t and country means with $\tilde{y_i} = \frac{1}{T}\sum y_{it}$; $\tilde{x}_i = \frac{1}{T}\sum x_{it}$; $\tilde{e}_i = \frac{1}{T}\sum e_{it}$ (T = number of periods). Both methods eliminate the intercept, but they only achieve the same estimation results when panels with two periods are considered (Baltagi, 2008).

Within Estimator: $y_{it} - \tilde{y}_i = \beta(x_{it} - \tilde{x}_i) + e_{it} - \tilde{e}_i$ [1]

First-Difference: $y_{it} - y_{it-1} = \beta(x_{it} - x_{it-1}) + e_{it} - e_{it-1}$ [2]

The decision which model should be preferred depends on a variety of factors. However, one important factor could be the presence of time-variant effects like non-stationarity (Wooldridge, 2010). Time-variant effects, to some degree, can be handled by taking growth instead of total values. For this reason, in cases where non-stationarity appears, we use the FD instead of the Within Estimator.

The Random Effects method (RE) assumes that heterogeneity varies randomly across country levels. RE can be estimated via Feasible General Least Squares (FGLS) (Greene, 2007).

A Breusch-Pagan Test is conducted to test for the existence of unobserved heterogeneity (Breusch and Pagan, 1979), the null hypothesis is homoscedasticity. A Maddala-Wu Unit-Root test is conducted to investigate the existence of non-stationarity (Maddala and Wu, 1999), the null hypothesis is non-stationarity. Moreover, we use the Hausman test to determine whether or not unobserved effects were country specific (Hausman, 1978), in our cases the null hypothesis is that the RE model gives the best fit.

Additionally, we applied an analysis which increases the level of detail in estimations through a differentiation between time and income groups (Buongiorno, 2015). Three time periods and two income levels were selected. The time limits were chosen to cover effects caused by the collapse of the Soviet Union, and those which were caused by financial crises after 2007. Therefore, regarding the time horizons, three relatively symmetric periods were chosen: 1992 to 1998, 1999 to 2006 and 2007 to 2014. Because it is likely that the income level of a country influences domestic wood markets, we split the list of countries into high income and low income groups by the world's average GDP per capita (World Bank, 2017).

Price elasticities are parameters to describe the behavior of markets. However, such parameters have to be tested for their plausibility before relying on these econometric results. In the present study tests on plausibility were conducted with a method which can simultaneously deal with demand, supply, trade and its interactions: an economic global forest products equilibrium model. In literature, there are several models which fit in such procedure. Most models were built in partial equilibrium frameworks and depend mainly on input specifications, which define market reactions (Romer, 2012). In contrast, coefficients in the form of market elasticities play a major role in such models: "…econometric methods may provide the necessary quantitative information for large-scale numerical models…" (Toppinen and Kuuluvainen, 2010, p 5). Some examples of these numerical models are the Global Forest Trade Model (GFTM, Jonsson et al., 2015), the European Forest Institute-Global Trade Model (EFI-GTM, Kallio et al., 2004) or the Global Forest Products Model (GFPM, Buongiorno et. al 2003). Based on those model frameworks, it is possible to simulate the behavior of wood markets caused by international developments as, e.g., described for the GFPM: "The GFPM is designed mainly as a policy analysis tool, to project the general future trends in quantities and prices at different stages of transformation, under different scenarios. " (Buongiorno et al., 2003, p 39).

In order to test our econometric estimation results, the present study uses a modified and extended version of the original GFPM as global partial equilibrium model. The GFPM, as originally described by Buongiorno et al. (2003), was chosen due to its open source character and its structure, which bases on FAOSTAT data (Figure 2.1).

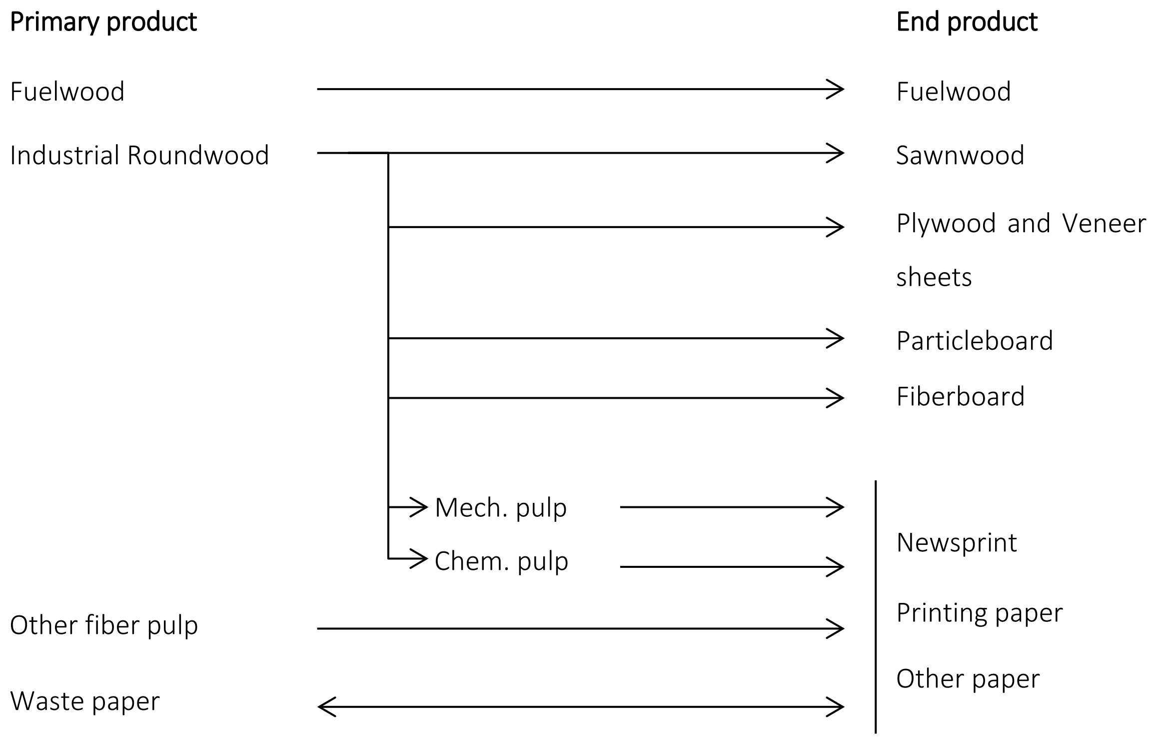

Figure 2.1 Production structure in original GFPM

Unlike in many other studies, the present study does not apply the GFPM to forecast market developments for policy analysis. We use the inherent model structure to plausibilize the wide range of market functions estimated below. For this purpose, the original GFPM had to be modified in order to match all aspects of markets considered in the study. In particular, the modifications target a separation of coniferous and non-coniferous industrial roundwood and sawnwood as described in Schier et al. (2018). Additionally, three types of industrial roundwood removals were implemented: industrial roundwood removals from primary2, secondary3 and planted4 forests. A similar approach was already undertaken by Buongiorno and Zhu (2014), where planted forests were implemented through exogenous shifts in the supply of wood in seven world regions. However, timber and forest type separation within the GFPM structure, combined with a more detailed data base for removals from planted and natural forests (Jürgensen et al. 2014), allow both a more detailed and more flexible simulation.

This modified GFPM is supplemented with results of econometric models below. To measure the performance of the modified model, we used the behavior of the original GFPM version as a benchmark. Further, the plausibility procedure entails the following order: First, the original and the modified GFPM are re-calibrated for all years from 1992 to 2012. Second, the time periods and simulation horizon are defined: for the present work the simulation horizon spans nine periods, each one year in length. Third, market simulations run from each starting year using the estimated market parameters and real GDP development as exogenous parameter. The amount of data resulting from 21 simulations of 9-period lengths is huge. A method to simplify the data is applied in two steps: In a first step, we compare the results of simulations with historical data to calculate the deviation between historical and simulated data:

$$\text{Deviation} = \frac{(\text{simulated value} - \text{historical data})}{\text{historical data}} \qquad [3]$$

Second, we calculated the standardized moments for this deviation, up to the third moment (skewness). These moments are used to validate the model. The mean of deviations is chosen as central moment. If it is high, the model will not simulate historical events properly. The variance of deviations (second moment) is used as parameter to measure the spread. Moreover, the skewness (third moment) is used as a hint for structural dysfunctions within the model. If the skewness is positive, the model will underestimate historical developments, and if it is negative the simulated structure tends to an overestimation in simulations.

One problem in calculating the deviation from historical to estimated developments refers to erroneous or omitted historical data as reported by the FAOSTAT. Since the GFPM correct these errors via a linear optimization procedure prior to market simulations (Buongiorno et al. 2003), calculating the deviation from GFPM and FAOSTAT data will therefore lead to infinite results in cases where the historical data is zero or omitted. Further, the

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[2] Primary forests are defined as “naturally regenerated forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed.” (FAO 2015)

[3] For secondary forests we used the FAO definition for “Other naturally regenerated forest”: “Naturally regenerated forest where there are clearly visible indications of human activities.” (FAO 2015)

[4] For planted forests we used the FAO definition: “Planted forests are composed of trees established through planting and/or through deliberate seeding of native or introduced species. “(FAO 2015)

deviation will be -1 if the historical data is non-zero, while the simulated value is zero. To deal with such errors, we exclude deviations below -0.99 and over 1.99. We also deal with outliers which are produced due to the model simulation. Model outliers can occur, e.g., due to breaks in time series data, which GFPM simulations cannot follow. The amount of such model outlier is 20,582 within the modified GFPM, which includes 691,992 data points in total. In the original GFPM version the amount is 23,299 and includes 1,119,032 data points in total (see Table 2.7). Due to limited data availability on wood removals from planted and natural forest, the number of countries in GFPM in the present study is reduced to 82 in the modified model version, compared to 180 countries in the original GFPM version.

2.3.2. Supply functions: Theoretical framework

In the following, it is assumed that timber production (S), in global wood markets, is defined as the removals from forests. The main theoretical driver in supply is the price (p_e) (Binkley and Dykstra, 1987). The prices of other consumable products (p_y) are necessary to describe timber production, too.

$$S = f(p_e, p_y) \qquad [5]$$

Assuming that people behave rationally and do not think in terms of nominal monetary units rather than in real ones, say, there is no monetary illusion:

$$S = f\left(\frac{p_e}{p_y}\right) \qquad [6]$$

$\frac{p_e}{p_y}$ can be defined as real export price p_{re}.

The production function (5) can be written in log-linear form, with α as intercept, β as a coefficient, which can be interpreted as price elasticity of the independent variable, and u as error term, which covers other minor influences:

$$ln\, S = ln\, \alpha + \beta_1\, ln\, p_{re} + lnu \qquad [7]$$

An exercise in estimating supply elasticities is to estimate effects caused by export prices on export quantities (E). Additionally to prices, export quantities of a certain good are strongly determined by the domestic production of exactly this good. Apart from this relationship, exports directly from storage or from imported quantities which are exported without further processing potentially have an impact on export quantities, too. However, because there is no data about the export from storage or the export from imported goods, this study concentrates on the relationship between export and production. Theory would imply a positive relationship. Therefore, estimation of price elasticities in international trade should include prices and production, if prices and production are not correlated with each other:

$$ln\, E = ln\, \alpha + \beta_2\, ln\, p_{re} + \beta_3 ln\, P + lnu \qquad [8]$$

2.3.3. Demand functions: Theoretical framework

In the following, it is assumed that the consumption of one product (C) depends on the price of the product (pi), the prices of other consumable products (py) and the domestic income (Y).

$$C = f(p_i, p_y, Y,) \qquad [9]$$

Assuming there is no monetary illusion, (8) can be written as:

$$C = f\left(\frac{p_i}{p_y}, \frac{Y}{p_y}\right) \qquad [10]$$

$\frac{p_i}{p_y}$ can be defined as real import price pri, while $\frac{Y}{p_y}$ is the real domestic income Yr.

From (9) a log-linear function can be derived, which was used as estimation model for demand:

$$ln\, C = ln\, \alpha + \beta_1\, ln\, p_{ri} + \beta_2\, ln\, Y_r + ln\, u \qquad [11]$$

α is used as intercept, β as a coefficient, which can be interpreted as price elasticity of the independent variable, and u as error term, which covers other minor influences. In economic theory for normal goods, the consumption decreases if the price rises and increases if the income rises.

2.3.4. Data

One major problem in global wood market analysis is to set up a reliable database. On a global scale, only few databases exist for the forest sector. One of these few covers the major forest products for as many as 207 countries and is collected by the FAO (FAO, 2017). Case studies have to be applied to complete this database with more detailed data. Such an approach is undertaken by Jürgensen et. al (2014), where removals of industrial roundwood from planted forests were quantified via national statistics and surveys in as many as 82 countries. These 82 countries were responsible for 96.2 % of global industrial roundwood production in 2012.

Due to the definition of total forest area as the sum of all planted and natural forest areas (FAO, 2015), the removal of industrial roundwood from natural forests can be calculated by subtracting planted forest removals from total industrial roundwood removals.

The production of total industrial roundwood worldwide comprised 1.766 million m³ in 2012 (FAO, 2017). The USA (347 million m³) was the biggest producer, followed by the Russian Federation (177 million m³) and China (159 million m³). It is notable that only 35 countries were responsible for more than 90 % of the world production (see Table 2.1).

The biggest producer of industrial roundwood from planted forests is the USA (141 million m³), followed by Brazil (132 million m³) and China (64 million m³). Natural forest removals were highest in the USA (206 million m³), Canada (118 million m³) and China (95 million m³). No information is given about the quantity removed from planted forests in Russia. Therefore, we excluded the Russian data on wood removals from the econometric estimations for natural and planted forests, assuming that the Russian industrial roundwood production is neither planted nor natural. However, the Russian industrial roundwood production is the second highest in the world, and cannot be omitted in global economic wood-product market modelling. Thus, for plausibility testing of estimated parameters with modified GFPM version, the Russian industrial roundwood production is assumed to be removed only from natural forests.

Table 2.1 Industrial Roundwood removals (in 1000 m³) by country in 2012

Country	Planted IndRound (by Jürgensen et. al, 2014)			Natural IndRound	IndRound Total
	Plantation Removal	SNPF Removal	Planted Total		
USA	101 934	39 562	141 496	205 580	347 076
Russia					177 455
China	64 240		64 240	95 323	159 562
Brazil	131 879		131 879	14 925	146 804
Canada	43	28 639	28 682	118 059	146 741
Sweden	1 150	10 412	11 562	52 037	63 599
Indonesia	12 530		12 530	50 076	62 606
India	43 060		43 060	6 457	49 517
Finland		18 893	18 893	25 721	44 614
Germany	10	20 435	20 445	22 418	42 863
Chile	38 351		38 351	724	39 075
Poland	951	27 494	28 445	4 528	32 972
New Zealand	27 454		**27 415**		27 415
France	9 300		9 300	15 645	24 945
Australia	19 211		19 211	4 286	23 497
Japan		13 681	13 681	4 798	18 479
South Africa	15 906		15 906	2 000	17 906
Malaysia	3 813		3 813	14 017	17 830
Turkey	3 500		3 500	14 201	17 701
Thailand	14 600		14 600		14 600

Czech Republic		13 467	**13 041**		13 041
Argentina	9 983		9 983	2 535	12 518
Spain	6 000	5 627	11 627		11 627
Latvia		2 101	2 101	9 256	11 357
Romania	81	4 546	4 627	6 423	11 050
Belarus		8 073	8 073	2 551	10 624
Portugal	9 565		9 565	546	10 111
Nigeria	3 300		3 300	6 118	9 418
United Kingdom	5 687	1 414	7 101	1 687	8 788
Norway	220	4 500	4 720	4 068	8 787
Ukraine	0	7 904	**7 851**	0	7 851
Viet Nam	3 700		3 700	3 100	6 800
Uruguay	7 937		**6 755**	0	6 755
Mexico	450		450	4 944	5 394
Estonia	0	560	560	4 804	5 364

Sources: Jürgensen et. al, 2014 and FAOSTAT, 2017
Note: SNPF = Semi-Natural Planted Forest; IndRound = Industrial Roundwood; Removals from planted forest = SNPF plus plantation removals; Natural IndRound = total industrial roundwood minus planted forest removals
Numbers in italics and bold: Total removals from planted forests were limited by the reported industrial roundwood production.

In addition to the FAOSTAT database, the International Tropical Timber Organization (ITTO) provides information on the production and trade of coniferous and non-coniferous plywood and veneer sheets. Both, the ITTO database and the FAOSTAT database are created on data obtained with the Joint Forest Sector Questionnaire (JFSQ). Since the databases share the source of data, the ITTO database is considered suitable to deliver data on the production and trade of coniferous and non-coniferous plywood and veneer sheets for the present study.

Income in the present study is defined as GDP per capita data which is taken from the World Bank's "World Development Indicators" for a period between 1992 and 2015, and from the World Bank's "Global Economic Prospects" for GDP outlook data in the period between 2016 and 2019.

2.4. Results

In the following we distinguish between supplied and demanded commodities in domestic and international markets. Here, supplied commodities are raw wood materials from the forests while demanded commodities are wood-based products which have undergone a certain transformation process.

2.4.1. Supply in domestic and international markets:

Again, as supplied commodities, we define products that come from the forest and which are not subject to further processing, namely industrial roundwood; industrial roundwood from planted or natural forests; coniferous, respectively non-coniferous industrial roundwood, fuelwood and coniferous respectively non-coniferous fuelwood. Due to limited trade data for industrial roundwood which distinguish between industrial roundwood from planted or natural forest, these two commodities were excluded from estimations on international wood supply, say exports. The same applies to coniferous, respectively non-coniferous, fuelwood. The implication is that this study cannot proof if there is any "trade effect" for these products. Table 2.2 describes the resulting price elasticities of supply. Most coefficients were insignificant which is surprising because theory and common literature, like Turner et al. 2006, suggest that price elasticities of supply are significantly positive. Price elasticities of export even are both strongly significant and negative while shifts in production influence exports positive. However, the price effect seems by far to rule out the production effect (see Table 2.3). The negative price elasticities of export may indicate that exports distorte the supply functions. Therefore we repeated the estimation procedure with domestic supply. As domestic supply, we define the supply which is produced only for domestic use which can be calculated by subtracting export from production. Results are presented in Table 2.4.

Table 2.2 Price elasticities of supply for roundwood products

	Price		adj. R²	Method
Commodity	Coefficient	SE		
Planted I.R.	0.2265	0.0503***	0.2758	RE
Natural I.R.	-0.1391	0.1112	0.2266	RE
Industrial Roundwood	-0.0003	0.0072	0.0000	FD
Industrial Roundwood C	0.0246	0.0121*	0.0026	FD
Industrial Roundwood NC	0.0022	0.0073	0.0000	FD
Fuelwood	-0.0150	0.0060*	0.0045	FD
Fuelwood C	0.0468	0.0289	0.0024	FE
Fuelwood NC	0.0052	0.0109	0.2294	RE

Note: This is a summarizing table; Elasticities are shown for the best model, which is chosen on the basis of Breusch-Pagan, Maddala-Wu, and Hausman tests.
SE = Standard Errors with *** for significance <0.001; ** for signi. <0.01; * for signi. <0.05 and . for signi.<0.1
Methods: OLS = ordinary least squares; FE = within estimator; FD = first-difference estimator; RE = random effects model

Table 2.3 Price elasticities of exports for selected roundwood products

	Price		Production		adj. R²	Method
Commodity	Coefficient	SE	Coefficient	SE		
Industrial Roundwood	-0.6989	0.0294***	0.3651	0.0766***	0.1740	FD
Industrial Roundwood C	-0.7737	0.0481***	0.3457	0.0988***	0.1430	FD
Industrial Roundwood NC	-0.6009	0.0336***	0.4002	0.0598***	0.1105	FE
Fuelwood	-0.7840	0.0339***	0.1047	0.1453	0.2704	FD

Note: This is a summarizing table; Elasticities are shown for the best model, which is chosen on the basis of Breusch-Pagan, Maddala-Wu, and Hausman tests.
SE = Standard Errors with *** for significance <0.001; ** for signi. <0.01; * for signi. <0.05 and . for signi.<0.1
Methods: OLS = ordinary least squares; FE = within estimator; FD = first-differnce estimator; RE = random effects model.

Table 2.4 Price Elasticities of domestic supply for selected roundwood products

	Price		adj. R²	Method
Commodity	Coefficient	SE		
Industrial Roundwood	0.0385	0.0116***	0.0039	FD
Industrial Roundwood C	0.0738	0.0186***	0.0361	RE
Industrial Roundwood NC	0.044	0.0117***	0.0054	FD
Fuelwood	0.0311	0.0131*	0.0035	FE

Note: This is a summarizing table; Elasticities are shown for the best model, which is chosen on the basis of Breusch-Pagan, Maddala-Wu, and Hausman tests.
SE = Standard Errors with *** for significance <0.001; ** for signi. <0.01; * for signi. <0.05 and . for signi.<0.1.
Methods: OLS = ordinary least squares; FE = within estimator; FD = first-differnce estimator; RE = random effects model

2.4.1.1. Wood removals from planted or natural forests:

The main data source for estimations related to the origin of wood is Jürgensen et al. (2014). Even though the scale of this data is limited, it includes production of 17 countries over a time period from 2000 to 2011. Notably, the data for 2012 covers 82 countries. However, for commodities related to the origin of wood (that is planted or natural forests) no price data exists. Instead, the real export price of industrial roundwood is used for estimations in this supply cluster because these commodities refers to the aggregate industrial roundwood production. Due to the limited time series information on the origin of wood and strong evidence for non-stationarity (due to Maddala-Wu tests) both FE models cannot be implemented in this estimation cluster. However, unobserved heterogeneity was found to occur in both datasets, due to Breusch-Pagan tests. Therefore, an FGLS estimator is suggested to give the best fit.

The results reveal that removals from natural forests do not respond significantly to price changes while the removals from planted forests do. This reaction of planted forest removals on price changes is, compared to other supply elasticities, strong (0.23 % change per 1 % price change).

2.4.1.2. Industrial roundwood:

Apart from planted and natural industrial roundwood, this study considers three different industrial roundwood commodities: coniferous and non-coniferous industrial roundwood, and an aggregated commodity which is the sum of coniferous and non-coniferous industrial roundwood. Data of all three industrial roundwood commodities is taken from FAOSTAT. They are calculated for 180 countries in a time series between 1992 and 2014. Maddala-Wu tests in all these datasets cannot reject the null hypothesis of non-stationarity, while unobserved heterogeneity can be found by the rejection of the null hypothesis in all Breusch-Pagan tests. Hausman tests address the heterogeneity as country specific; therefore, FD estimations were used to estimate price elasticities of supply of industrial roundwood.

In general, the price effect on industrial roundwood supply is low, and for the aggregated industrial roundwood commodity even negative (-0.0003). However, the coniferous commodity rises 0.025 % when the price rises 1 %. The coefficient of the non-coniferous commodity responds even less and is insignificant (see Table 2.2).

Export quantities depend strongly negatively on real export prices and are significantly positive dependent on production (see Table 2.3). The estimation procedure is repeated for price elasticities in domestic supply. The so obtained price effect shows significant positive implications for all industrial roundwood commodities. However, all estimated elasticities are below 0.1 %, for a 1 % price change. It is remarkable that coniferous wood responds more strongly to price changes than non-coniferous wood (see Table 2.4).

Our analysis of time effects show that the price elasticities in the non-coniferous wood decreases from 0.058 between 1992 and 1998 to 0.04 between 2007 and 2014. In the same period, the price reaction in coniferous wood increases from 0.066 to 0.091, while the response in the aggregate industrial roundwood decreases from 0.045 to 0.034. The coefficients of the aggregated industrial roundwood and the non-coniferous wood are within the ranges of its standard errors, which means there is no significant difference between these two products. However, the difference between these two wood forms and the coniferous industrial roundwood differ significantly from 1999 (see Table 2.10 in the Appendix).

2.4.1.3. Fuelwood:

Available data on the trade of fuelwood does not distinguish between its coniferous and non-coniferous parts. Therefore, it is assumed that both parts can be traded as full substitutes. The price of the fuelwood aggregate is therefore used for both coniferous and non-coniferous fuelwood. However, neither the coniferous nor the non-coniferous fuelwood responds to price variations. In contrast, the aggregated production responds significantly negative to price changes (see Table 2.2).

Price elasticities of exports reveal that export quantities depend strongly negative on real export prices but are independent of production (see Table 2.3). Repeating the estimation procedure for domestic supply gives small but significant positive reactions of domestic supply on price changes (see Table 2.4).

2.4.2. Demand in domestic and international markets:

As demanded commodities we define fiberboard, fuelwood, newsprint, other paper, printing and writing paper, particle board, plywood & veneer sheets and sawnwood. Sawnwood and plywood & veneer sheets are separated into non-coniferous and coniferous commodities. Resulting elasticities of demand were always negative significant for price elasticities and positive significant for income elasticities (see Table 2.5). These results confirm the theory above and are in line with current literature (Simangunsong and Buongiorno 2001, Michinaka et al. 2011 and Buongiorno 2015).

Estimating price elasticities in international trade deepen the understanding of wood markets (Turner and Buongiorno, 2004). A nearly one to one relation between prices and consumption could be shown in most demanded products in international wood trade (see Table 2.6). Compared with import, domestic demand seems relatively inelastic.

Table 2.5 Price elasticities of demand

	Price		Income		adj. R^2	Method
Commodity	Coefficient	SE	Coefficient	SE		
Fiberboard	-0.4629	0.0504***	1.0661	0.0401***	0.4095	RE
Fuelwood	-0.1458	0.0312***	0.5680	0.0629***	0.0965	FE
Fuelwood C	-0.0231	0.0444	0.0449	0.0696	0.1453	RE
Fuelwood NC	-0.0376	0.0176*	0.1446	0.0372***	0.0198	FE
Newsprint	-0.1208	0.0256***	0.2371	0.0704***	0.0331	FD
Other Paper	-0.1695	0.0366***	0.2283	0.0603***	0.0142	FD

P. & W. Paper	-0.5188	0.0484***	0.3626	0.0795***	0.0861	FD
Particle Board	-0.4923	0.0476***	0.7502	0.1274***	0.1026	FD
Plywood & Veneer	-0.3534	0.0273***	0.596	0.0777***	0.1088	FD
Plywood & Veneer C	-0.5533	0.0477***	0.6312	0.1616***	0.0789	FD
Plywood & Veneer NC	-0.3111	0.0280***	0.6375	0.0893***	0.083	FD
Sawnwood	-0.1260	0.0241***	0.19	0.0721**	0.0166	FD
Sawnwood C	-0.3001	0.0404***	0.4409	0.1276***	0.0403	FD
Sawnwood NC	-0.1221	0.0250***	0.2162	0.0914*	0.0156	FD

Note: This is a summarizing table; Elasticities are shown for the best model, which is chosen on the basis of Breusch-Pagan, Maddala-Wu, and Hausman tests.
SE = Standard Errors with *** for significance <0.001; ** for signi. <0.01; * for signi. <0.05 and . for signi.<0.1. Methods: OLS = ordinary least squares; FE = within estimator; FD = first-differnce estimator; RE = random effects model

2.4.2.1. Sawnwood

Evidence for non-stationarity was found in most sawnwood datasets on the basis of Maddala-Wu test results. At the same time, unobserved heterogeneity can be addressed as country specific, through Breusch-Pagan and Hausman tests. Therefore, the FD Model was the preferred method in this cluster. Unobserved country effects vary randomly across countries only with regard to the import elasticity of non-coniferous sawnwood. Therefore the random effect model was used only for estimations of this commodity. The results confirm the theory above; demand shows a negative price elasticity and a positive income elasticity (see Table 2.6).

Table 2.6 Price elasticities of imports

	Price		Income		Production		adj. R²	Method
Commodity	Coefficient	SE	Coefficient	SE	Coefficient	SE		
Fiberboard	-0.7095	0.0463***	1.0629	0.1267***	-0.0449	0.0302	0.2421	FD
Fuelwood	-0.9334	0.0569***	0.8550	0.1196***	0.0865	0.1272	0.2515	FE
Newsprint	-0.3171	0.1499*	0.4782	0.0930***	-0.2168	0.0556***	0.0609	FE
Other Paper	-0.4511	0.0437***	0.4485	0.0721***	0.0023	0.0297	0.0745	FD
P. & W. Paper	-0.9601	0.0662***	0.5533	0.0815***	0.0103	0.0217	0.1749	FD
Particle Board	-0.5289	0.0527***	0.9223	0.1547***	-0.0865	0.0515 .	0.0911	FD
Plywood & V.	-0.9963	0.0430***	0.8722	0.1051***	-0.0214	0.0396	0.2637	FD
Plywood & V. C	-1.2328	0.0580***	1.1499	0.1573***	-0.0535	0.0455	0.2949	FD
Plywood & V. NC	-1.0245	0.0423***	0.9836	0.1246***	-0.1060	0.0425*	0.2890	FD
Sawnwood	-0.9100	0.0486***	0.8089	0.1630***	0.1651	0.0722*	0.2178	FD

Sawnwood C	-0.5913	0.0543***	1.1323	0.1750***	-0.0178	0.0643	0.2949	FD
Sawnwood NC	-0.9331	0.0442***	0.7538	0.0487***	0.3048	0.0409***	0.2416	RE

Note: This is a summarizing table; Elasticities are shown for the best model, which is chosen on the basis of Breusch-Pagan, Maddala-Wu, and Hausman tests.
SE = Standard Errors with *** for significance <0.001; ** for signi. <0.01; * for signi. <0.05 and . for signi.<0.1. Methods: OLS = ordinary least squares; FE = within estimator; FD = first-differnce estimator; RE = random effects model

Congruent with the supplied industrial roundwood commodities, coniferous sawnwood responds more strongly to price changes than the non-coniferous commodity. Price elasticities turned out to be stronger in low-income countries for coniferous sawnwood, while the price elasticities are stronger in high-income countries for non-coniferous sawnwood (see Table 2.11 in appendix).

In the sawnwood cluster, price elasticities are similar across different time periods. The most elastic price reaction can be found for a time horizon between 1999 and 2006 for all sawnwood commodities (see Table 2.11 in appendix).

2.4.2.2. Plywood and Veneer sheets:

Price elasticities of plywood & veneer sheets are similar to the ones obtained for the sawnwood cluster, but always more price elastic. Again, low-income countries seem to be more price elastic for coniferous plywood and veneer sheets, while in high-income countries the price elasticity of demand for non-coniferous plywood and veneer sheets is more price elastic (see Table 2.5). There were no effects in coniferous plywood and veneer sheets resulting from different time horizons (always around -0.55), while price effects in non-coniferous plywood and veneer sheets decrease from -0.362 between 1992 and 1998 to -0.271 between 2007 and 2014 (see Table 2.11 in appendix).

2.5. Plausibility Testing

The econometric estimations of supply, demand, and trade elasticities were implemented in the modified GFPM version. In accordance with the description in the methodology chapter, a validation of simulation results was undertaken after finishing the simulation procedure. The key component of this validation is the comparison of simulation results obtained with the original and the modified GFPM. It shows that the modified model structure leads to slightly different outcomes compared to the original model.

Differences in initial resources allocation between original and modified GFPM can be found. Thus, these differences can be explained due to the re-calibration and the underlying calibration procedure (for details see Schier et al., 2018) together with a different modeling structure. Figures 2.2 and 2.3 show the differences in the development between the GFPM with new elasticities (Figure 2.2) and the original elasticities (Figure 2.3).

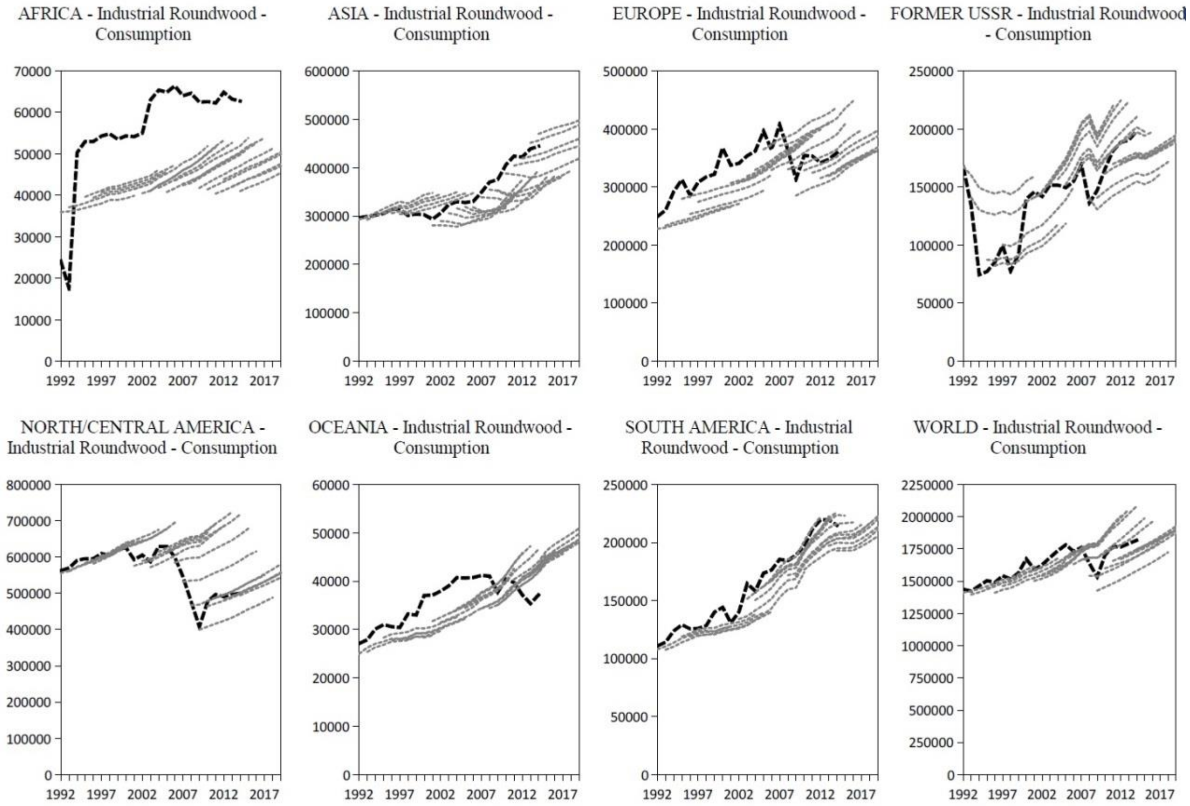

Figure 2.2 Results obtained with the modified GFPM and re-estimated econometric parameters in 1000 m³

Note: Black line = historical data (FAO, 2017, Grey lines = GFPM scenario results with newly derived parameters. 21 GFPM scenarios were simulated, each for one starting year in a time period between 1992 - 2012. Each scenario simulates nine periods with a length of one year each. GFPM scenarios were built with historical GDP development and GDP forecasts (2016 to 2019) both provided by the World Bank.

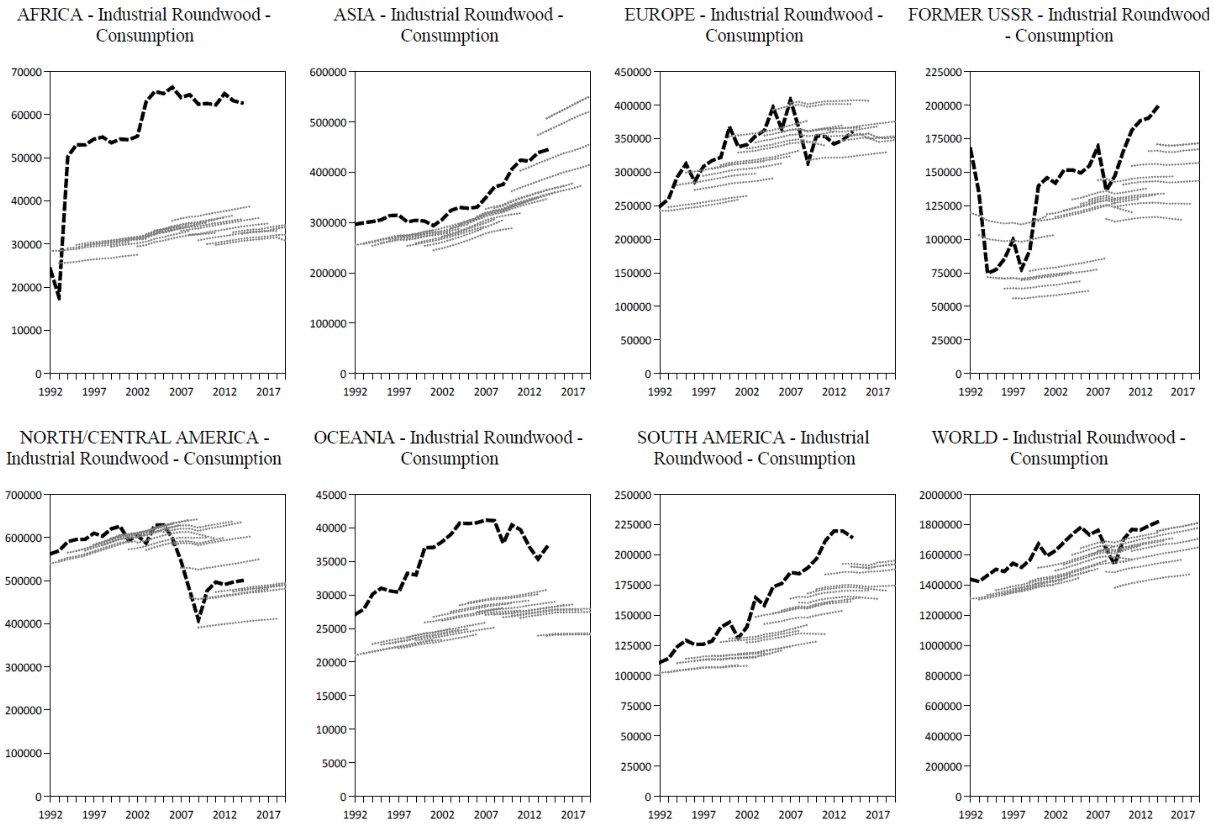

Figure 2.3 Original GFPM results in 1000 m³

Note: Black line = historical data (FAO, 2017), Grey lines = GFPM simulation results with original parameters. 21 GFPM scenarios were simulated, each for one starting year in a time period between 1992 - 2012. Each scenario simulates nine periods with a length of one year each. GFPM scenarios were built with historical GDP development and GDP forecasts (2016 to 2019) both provided by the World Bank.

For statistical analysis the deviation from the simulated to historical value is calculated and adjusted in order to address outliers in data, as mentioned in the methodology chapter. In the modified model version, the mean deviation (central moment) is -0.018 using the new elasticities (see Table 2.7). This is slightly more accurate than the original model with a mean of -0.029. The standard deviation (second moment) and variance to the central moment in both models is relatively high but lower in the model with the new structure (a standard deviation of 0.514 and a variance of 0.264 for new model structure and a standard deviation of 0.522 and a variance of 0.273 in the original model). These relatively high standard deviations can be explained by the scope of data the GFPM covers. As a model, the GFPM is a simplified representation of reality and thus, simulation results cannot fit reality into every detail. However, the third moment (deviation's skewness) provides information about the structural distribution of deviations from simulated to historical data. These deviations can be interpreted as over- or underestimation. Skewness near zero would suggest that the model is normally distributed around the historical data. Here, the skewness of both GFPM versions, the original and the modified, is positive. Therefore, both models structurally underestimate the developments in reality (modified model skewness 0.807, original model skewness 0.785). The difference in skewness of both models is relatively small, but the modified model seems to underestimate historical data more.

Table 2.7 Validation of the modified GFPM

	mean deviation to historical data	standard deviation	variance	skewness	quantity of data	quantity of outliers
Modified GFPM	-0.018	0.514	0.264	0.807	691992	20582
Original GFPM	-0.029	0.522	0.273	0.785	1119032	23299

To sum up, the GFPM structure with new elasticities and a separation of forest types simulate historical events more accurately, with nearly the same variance, and underestimate historic events more than the original GFPM. Therefore, inelastic price elasticities in supply, negative price elasticities in demand and import driven trade leads to GFPM simulation results which are in line with historical development and the original GFPM. In conclusion we assume that such a modified GFPM version with the new elasticities estimated in the present study behave plausibly.

2.6. Discussion and Conclusion

The present study is built on a relatively thin data basis. Only 82 countries were included in the estimation procedure for planted and natural forest removals. The Russian Federation is the biggest producer of industrial roundwood, for which this study could not differntiate between planted or natural industrial roundwood removals. Therefore, it is possible that our results were to some degree distorted. For future studies on this field it would be helpful to get data about the price and trade of global industrial roundwood from different origins. This database could offer new possiblities in studying how timber production and the demand for wood can develop in times when forest protection, biodiversity and carbon emissions became more and more important. Two other issues addressed in this work are the global approach and domestic price data. The problem with the global approach is that country specific or regional issues were ignored to some degree. This effect could lead to contradicted results in regional or country specific studies. However, future studies can improve the present research with detailed econometric work in different regions and consideration of how they interact with each other. Problems with domestic price data occur because no data for domestic prices exists on a global scale. Thus, we had to approximate such data. We use import prices for elasticities in demand and export prices for elasticities in supply.

One objective of the present study was to provide further knowledge about economic effects on the quantities harvested from planted forest. We found that the timber production from planted and from natural forests behaves differently. While for removals from planted forests there is a positive significant response to price changes, removals from natural forests lack such a response. This outcome could occur because of the economic motive which seems to be behind planting forests, while the effect in natural forests could eventually be explained by its use to satisfy demand. Further econometric work, especially for wood supply, should be aware of such bahvior. The correlations between prices and harvest could depend on the share of removals from planted forests in a specific region or even in a specific country.

As another key result, we found that price and income elasticities in demand behave as predicted by economic theory, while price elasticities of both imports as well as exports are significantly negative. These results can be interpreted in a way that the trade of wood commodities is driven by demand in international markets. This means if the demand for wood imports increases globally, the exports of wood will follow subsequently; price mechanisms for global trade would be withdrawn.

Further examination of the relationship between prices and wood supply were undertaken by estimating price effects in supply which were produced only for domestic markets. This domestic supply behaves in significant positive dependence to price changes. However, it could be shown that these effects are quite low (see Table 2.4). This conclusion, together with an overall low coefficient of determination, could lead to the recognition that prices have only little influence on the removals from forests on a global scale, even though the results for regional markets could be contradicted, e.g., in subsequence to the share of planted forest removals as mentioned above. The implication for supply is: other influential variables for timber production on global scale need to be found apart from prices. Efforts to identify such omitted variables were already undertaken, e.g., in Turner et al. (2006) with an approach to define global supply, by Beach et al. (2005) which present a synthesis for effects resulting because of different types of ownership, or by Prestemon and Wear (2000) with an approach to link individual harvest choices to aggregated timber supply. However, estimating price elasticities in markets with storable commodities can lead to problems apart from adding independent variables into the estimation procedure. One can occur because shocks in wood supply can be compensated through storage building. Such behavior influences price mechanism and bias estimations, even if the shock is located some time periods earlier or if it is expected to happen in the future. Roberts and Schlenker (2013) had undertaken an approach implementing shocks in the estimation of supply and demand for agricultural commodities. In forest product markets such shocks could be described, e.g., by weather disasters (Prestemon and Holmes, 2004, Prestemon and Holmes, 2010 or Kinnucan, 2016).

Future studies should take such behavior into account and deal with the omitted variables in supply as well as demand, because in demand, too, the coefficient of determination is quite low. So, the conclusions in both estimation clusters are similar: some other dependencies, which are not considered in this work, exist. In demand, these other determinants could be material substitution in end-product markets (Jochem et al., 2016) or population growth (Alexandratos, 1995). In contrast to supply, the demand cluster seems in line with basic economic theory for normal goods.

In contradiction to other studies which calculate income elasticities for newsprint, e.g., Hetemäki and Obersteiner (2001), the present study does not find an indication for decreasing income elasticities for newsprint. Although we did not find negative or zero income elasticities, it could be imagined that possible future studies, on global scale, find evidence for such relationship since such an effect is assumed to arise in succession of a rising demand for digital information technology which could replace newsprint (Hetemäki, 2013). Basically, since 2008 the global newsprint production has decreased about 36% (FAOSTAT 2017).

Other key findings of the present study are: First, trade elasticities are more likely dependent on price and income changes than price elasticities of domestic markets. Second, coniferous wood products react more strongly to price changes than equivalent non-coniferous wood products. This is shown for supply as well as for demand. Third, estimated responses of fuelwood supply (see Table 2.8 in appendix) point out that significant positive effects only occur in high-income countries. This significant positive effect bolsters the assumption, that low-income countries use fuelwood independent of prices, while high-income countries can decide on the type of fuel to be used. This is in line with the current literature of the energy stack behavior: Fuelwood is utilized complementarily and not substitutionally with increasing income (van der Kroon et al., 2013).

The present study uses the inherent model structure of the GFPM to verify the wide range of market functions which we have estimated. As a result we found that the model with elasticities estimated in this work behaves in line with historical data and the original model. Moreover, the modified version of GFPM could help to study how production of roundwood from planted forests will develop further and how this might impact the supply from natural forest and wood markets in the future.

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2.8. Appendix

Table 2.8 Forest area in different regions

Region in FRA	Domain in FRA	Year	Forest in 1 000 ha	Primary Forest in 1 000 ha	Secondary Forest In 1 000 ha	Planted Forest In 1 000 ha
Africa	subtropics	2015	6 722.00	0.00	5 273.90	1 448.10
Africa	tropic	2015	617 380.63	135 048.15	441 089.93	14 876.69
Asia	temperate	2015	244 933.40	29 449.00	130 979.10	83 405.90
Asia	subtropics	2015	58 881.90	7 074.24	34 662.09	15 295.40
Asia	tropic	2015	289 546.30	80 757.94	178 942.48	29 844.56
Europe	boreal	2015	877 382.78	275 524.81	559 937.15	41 920.68
Europe	temperate	2015	101 549.98	1 183.50	57 956.71	35 408.81
Europe	subtropics	2015	36 549.72	310.90	31 562.07	4 676.85
North and Central America	boreal	2015	347 069.00	205 924.00	125 361.00	15 784.00
North and Central America	temperate	2015	310 097.80	75 300.00	208 433.80	26 364.00
North and Central America	subtropics	2015	66 040.00	33 056.00	32 897.00	87.00
North and Central America	tropic	2015	27 445.71	5 674.86	20 606.18	1 084.81
Oceania	subtropics	2015	124 751.46	5 039.00	117 695.00	2 017.00
Oceania	temperate	2015	10 152.00	2 160.00	5 905.00	2 087.00
Oceania	tropic	2015	38 620.12	19 660.73	18 155.66	276.52
South America	subtropics	2015	27 112.00	1 738.00	24 172.00	1 202.00
South America	temperate	2015	17 735.00	5 355.00	9 336.00	3 044.00
South America	tropic	2015	797 163.62	393 364.10	334 592.84	10 775.84

Source: Forest research assessment (FRA) 2015

Table 2.9 Industrial Roundwood removals (in 1000 m³) by country in 2012

Country	Planted IndRound (by Jürgensen et. al, 2014)			Natural IndRound	IndRound Total (FAO, 2017)
	Plantation Removal	SNPF Removal	Planted Total		
Russian Federation					177 455 000
China	64 239 744		64 239 744	95 322 556	159 562 300
Brazil	131 878 975		131 878 975	14 925 025	146 804 000
Canada	43 050	28 639 000	28 682 050	118 058 950	146 741 000
Sweden	1 150 000	10 412 000	11 562 000	52 037 000	63 599 000
Indonesia	12 530 000		12 530 000	50 075 500	62 605 500
India	43 059 944		43 059 944	6 457 056	49 517 000
Finland		18 893 000	18 893 000	25 721 134	44 614 134
Germany	10 000	20 435 000	20 445 000	22 417 602	42 862 602
Chile	38 350 928		38 350 928	724 072	39 075 000
Poland	950 601	27 494 000	28 444 601	4 527 689	32 972 290
New Zealand	27 453 946		27 415 000	0	27 415 000
France	9 300 000		9 300 000	15 645 180	24 945 180
Australia	19 210 883		19 210 883	4 286 117	23 497 000
Japan		13 681 000	13 681 000	4 798 000	18 479 000
South Africa	15 906 387		15 906 387	1 999 972	17 906 359
Malaysia	3 813 445		3 813 445	14 016 555	17 830 000
Turkey	3 500 000		3 500 000	14 201 000	17 701 000
Thailand	14 600 000		14 600 000	0	14 600 000
Czech Republic		13 467 000	13 041 000	0	13 041 000
Argentina	9 983 181		9 983 181	2 534 819	12 518 000
Spain	6 000 000	5 627 000	11 626 795	0	11 626 795
Latvia		2 101 000	2 101 000	9 255 587	11 356 587
Romania	81 341	4 546 000	4 627 341	6 422 996	11 050 337
Belarus		8 073 000	8 073 000	2 551 000	10 624 000
Portugal	9 564 947		9 564 947	545 866	10 110 813
Nigeria	3 300 000		3 300 000	6 118 000	9 418 000
United Kingdom	5 686 958	1 414 000	7 100 958	1 686 589	8 787 547
Norway	219 685	4 500 000	4 719 685	4 067 723	8 787 408
Ukraine		7 904 000	7 850 800	0	7 850 800
Viet Nam	3 700 000		3 700 000	3 100 000	6 800 000
Uruguay	7 937 394		6 755 000	0	6 755 000
Mexico	450 000		450 000	4 944 000	5 394 000
Estonia		560 000	560 000	4 804 000	5 364 000
Myanmar	920 440		920 440	4 066 560	4 987 000
Uganda	349 000		349 000	3 984 000	4 333 000
Belgium	32 930		32 930	4 202 318	4 235 248
Croatia	118 384		118 384	4 038 616	4 157 000
Paraguay	558 902		558 902	3 485 098	4 044 000
Philippines	3 791 559		3 791 559	106 441	3 898 000
Korea, Republic of		776 000	776 000	3 082 000	3 858 000
Colombia	700 000		700 000	3 141 000	3 841 000
Papua New Guinea	100 000		100 000	3 594 208	3 694 208
Bulgaria	225 447		225 447	2 831 278	3 056 725
Hungary	2 906 000		2 906 000	81 197	2 987 197
Ethiopia	150 000		150 000	2 785 000	2 935 000
Ireland	2 375 654		2 375 654	0	2 375 654

Côte d'Ivoire	130 000		130 000	2 226 000	2 356 000
Italy	656 800		656 800	1 699 175	2 355 975
Ecuador	2 200 000		2 200 000	134 000	2 334 000
Congo, Republic of	385 548		385 548	1 935 575	2 321 123
Solomon Islands	250 000		250 000	1 880 000	2 130 000
Cameroon	236 000		236 000	1 819 000	2 055 000
Ghana	105 286		105 286	1 926 714	2 032 000
Gabon	213 250		213 250	1 586 750	1 800 000
Laos	3 316		3 316	1 528 684	1 532 000
Peru	603 483		603 483	865 517	1 469 000
Malawi	260 000		260 000	1 140 000	1 400 000
Denmark	1 000 000		1 000 000	330 904	1 330 904
Zambia	662 500		662 500	662 500	1 325 000
Serbia	375 049		375 049	941 951	1 317 000
Costa Rica	827 297		827 297	476 703	1 304 000
Venezuela, Boliv Rep of	708 510		708 510	587 490	1 296 000
Rwanda	432 000		432 000	779 927	1 211 927
Kenya	1 037 700		1 032 000	0	1 032 000
Fiji Islands	375 000		375 000	425 000	800 000
Iran, Islamic Rep of	420 000		420 000	310 000	730 000
El Salvador	54 259		54 259	627 741	682 000
Burundi	247 282		247 282	369 718	617 000
Sri Lanka	100 000		100 000	511 000	611 000
Cuba	315 200		315 200	245 800	561 000
Guatemala	5 405		5 405	537 551	542 956
Benin	62 000		62 000	460 000	522 000
Zimbabwe	259 200		259 200	220 400	479 600
Suriname	2 000		2 000	433 189	435 189
Honduras	4 314		4 314	376 686	381 000
Morocco	448 000		361 000	0	361 000
Swaziland	1 000 000		330 000	0	330 000
Bangladesh	210 000		210 000	72 000	282 000
Panama	176 200		176 200	13 800	190 000
Togo	66 400		66 400	99 600	166 000
Trinidad and Tobago	10 000		10 000	55 000	65 000
Uzbekistan	8 000		8 000	2 000	10 000
sum	560 934 006	208 084 000	766 554 561	757 501 797	701 511 358

Sources: Jürgensen et. al, 2014 and FAOSTAT, 2017

Note: SNPF = Semi-Natural Planted Forest; IndRound = Industrial Roundwood; Removals from planted forest = SNPF plus plantation removals; Natural IndRound = total industrial roundwood minus planted forest removals

Table 2.10 Detailed results obtained for the price elasticities of domestic supply for three different time series and two different income groups for selected roundwood products

		Price	
Commodity	Separated by	Coefficient	SE
Industrial Roundwood	1992-1998	0.0451	0.0128***
	1999-2006	0.0389	0.0121**
	2007-2014	0.0344	0.0122**
	High Income	0.0812	0.0315**
	Low Income	0.0361	0.0141*
Industrial Roundwood C	1992-1998	0.0662	0.0187***
	1999-2006	0.0893	0.0194***
	2007-2014	0.0909	0.0190***
	High Income	0.0587	0.0348.
	Low Income	0.0832	0.0211***
Industrial Roundwood NC	1992-1998	0.0583	0.0136***
	1999-2006	0.0473	0.0124***
	2007-2014	0.0398	0.0119***
	High Income	0.0129	0.0267
	Low Income	0.0514	0.0132***
Fuelwood	1992-1998	-0.0051	0.0149
	1999-2006	-0.0063	0.014
	2007-2014	0.0294	0.0129*
	High Income	0.0962	0.0198***
	Low Income	-0.022	0.0180

Note: SE = Standard Errors with *** for signi. <0.001; ** for signi. <0.01; * for signi. <0.05 and for signi <0.1

Table 2.11 Detailed results obtained for the price elasticities of domestic demand for three different time series and two different income groups for plywood and sawnwood products

		Price Coefficient	SE	Income Coefficient	SE
Plywood	1992-1998	-0.3987	0.0311***	0.6127	0.0816***
	1999-2006	-0.3128	0.0340***	0.5413	0.0813***
	2007-2014	-0.2793	0.0419***	0.5249	0.0827***
	High Income	-0.3096	0.0867***	0.6237	0.1553***
	Low Income	-0.3551	0.0291***	0.5819	0.0937***
Plywood C	1992-1998	-0.5489	0.0554***	0.5729	0.1704***
	1999-2006	-0.5500	0.0595***	0.5716	0.1690***
	2007-2014	-0.5694	0.0830***	0.5997	0.1715***
	High Income	-0.2263	0.1286.	0.6794	0.3088*
	Low Income	-0.5991	0.0523***	0.5498	0.1973**
Plywood NC	1992-1998	-0.3617	0.0339***	0.6576	0.0941***
	1999-2006	-0.2619	0.0348***	0.5768	0.0933***
	2007-2014	-0.2706	0.0417***	0.5909	0.0942***
	High Income	-0.5662	0.0876***	0.7971	0.1747***
	Low Income	-0.2777	0.0297***	0.6319	0.1077***
Sawnwood	1992-1998	-0.1395	0.0374***	0.2225	0.0875*
	1999-2006	-0.1571	0.0341***	0.2522	0.0875**
	2007-2014	-0.1255	0.0300**	0.2302	0.0875**
	High Income	-0.2212	0.0944*	0.6471	0.1335***
	Low Income	-0.1287	0.0293***	-0.0283	0.1119
Sawnwood C	1992-1998	-0.1823	0.0575**	0.3147	0.1339*
	1999-2006	-0.4639	0.0492***	0.4965	0.1331***
	2007-2014	-0.2259	0.0560***	0.3534	0.1350**
	High Income	-0.1564	0.1318	0.8088	0.2836**
	Low Income	-0.3189	0.0428***	0.333	0.1447*
Sawnwood NC	1992-1998	-0.082	0.0359*	0.1729	0.0985.
	1999-2006	-0.1842	0.0362***	0.258	0.0975**
	2007-2014	-0.1137	0.0360**	0.2055	0.0973*
	High Income	-0.4415	0.0886***	0.5837	0.1607***
	Low Income	-0.0911	0.0272***	0.0697	0.1171

Note: SE = Standard Errors with *** for signi. <0.001; ** for signi. <0.01; * for signi. <0.05 and . for signi <0.1

3. Estimating supply and demand elasticities of dissolving pulp, lignocellulose-based chemical derivatives and textile fibres in an emerging forest-based bioeconomy

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3.1. Abstract

In a growing bioeconomy, traditional forest products markets change and diversify. Fossil-based inputs in the chemical, textile, apparel and downstream industries can be replaced by lignocellulose-based products such as dissolving pulp, cellulose-based chemical derivatives and textile fibres. When looking ahead, these previous niche products are likely to gain in economic importance. So far, little attention has been paid to the characteristics of macroeconomic relations of emerging lignocellulose-based materials on macroeconomic level. Key economic parameters for such materials are not available neither at regional nor at global level. This work aims to contribute to a better understanding of the market behavior of emerging forest products that are not yet covered by forest products market analysis. Therefore, this paper investigates how lignocellulose-based products respond to changes of main economic drivers and compute global market elasticities for dissolving pulp, cellulose-based chemical derivatives and textile fibres. To conduct our evaluation, we first test historical input data for non-constancy in time series due to structural changes using change-point estimator (MOSUM test). We subsequently carry out a global econometric analysis of demand and supply elasticities with income (GDP) and real import and export prices as explanatory variables. By doing so, we deliver key information for the adaptation of forest-product market analysis and modelling to an upcoming bioeconomy. The results show several structural changes especially in price data between 1992 and 2015, thus supporting the use of time series cuts to divide the time line from 1992 to 2015 into three different sub-periods. Elasticities are subsequently estimated for each of the sub-periods. The results from this econometric analysis provide import demand and export supply elasticities of dissolving pulp, cellulose chemical derivatives and cellulose textile fibres. In addition, we present elasticity estimation for the apparent consumption of dissolving pulp. Our findings outline the significant relationship between both export supply and import demand volumes and relative changes in prices and income. Across time periods, elasticities of cellulose-based derivatives and textile fibres do not show a clear trend towards more elastic or inelastic coefficients. However, the price elasticities of dissolving pulp fluctuate strongly from inelastic to highly elastic over time. Elasticity estimates of export supply indicate that it is sensitive to international competitiveness which in turn is governed by international demand. Finally, we statistically show that the estimated price and income elasticities of import demand can be analogously interpreted as the demand elasticity of apparent consumption. This is of great importance for economic equilibrium models, such as GFPM or EFI-GTM, in order to simulate and analyze forest sector developments and scenarios.

3.2. Introduction

Forest and wood-based product markets are of economic importance at local and global level. First signs of shifting patterns and structural changes in traditional wood products markets occurred at the end of the last millennium. The global economic crises in 2007–2008, the subsequent market consolidation in North America and Europe, and the growth of Asian economies shift economic power and bring forth new consumer and producer markets. Globally, rises in income lead to a growing demand for wood-based products, especially in Asian markets (Figure 3.1). At the same time, increasing environmental awareness leads to a growing demand for bio-based products.

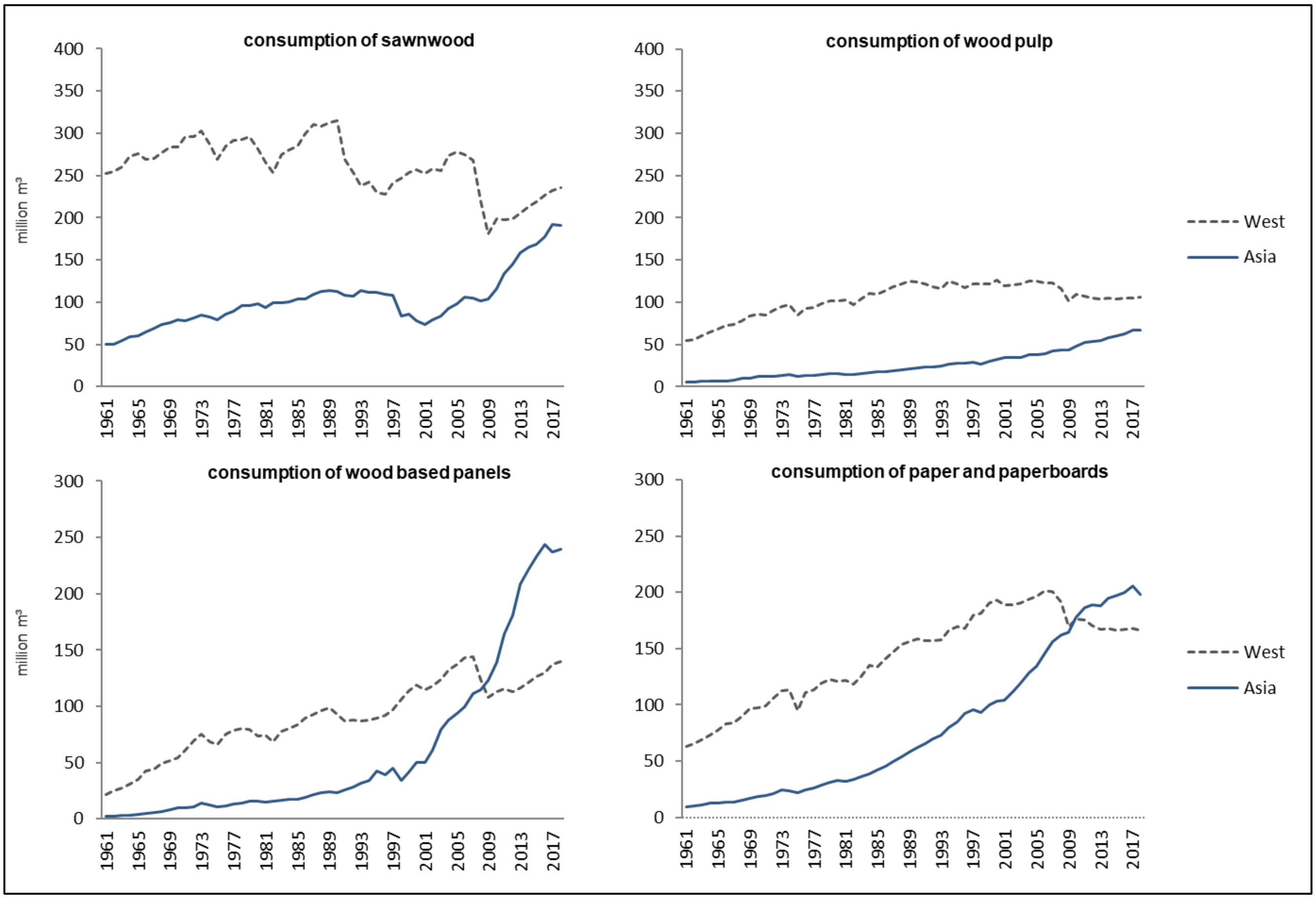

Figure 3.1 Shifting demand pattern in wood products markets from Western to Eastern markets

Data: FAOStat (2019b)

The term “bioeconomy” has originated from discussions of alternative socio-economic concepts, aiming at shifting economies into more sustainable pathways. Among a variety of bio-based raw materials, wood is traditionally an all-rounder (Andersson et al. 1986). This makes the forest-based industry an integral part of any bio-based economy. In this way, the forest-based sub-sectors are becoming an increasingly diverse supplier of commodities to a wider range of industries. We expect that current socio-economic developments foster the growth of new economic values for wood. In particular, the global textile and apparel market is expected to grow dynamically in the upcoming years, due to increasing global population and income levels (Haemmerle 2011) since its growth is expected to highly depend on these two variables (Kozlowski et al. 2016). In 2018, the share of lignocellulosic fibres in the total textile fibre mix accounted for approximately 6% (Textile World, 2021). At the same time, the output of the cellulosic fibre cotton is likely to stagnate (Haemmerle 2011; Chen et al. 2016) as this raw material competes with crops for land, water, and fertilizers (Kumar and Christopher 2017). A proportionally decreasing cotton supply with an increasing demand for textile fibres could lead to a gap in the supply of cellulosic fibres (Haemmerle 2011). This gap could be filled with, e.g., lignocellulosic fibres from wood (Chen et al. 2016). Here, factors like the environmentally sound characteristics of lignocellulosic fibres, changes in consumer preferences regarding fashion styles, and advanced production technologies can lead to a disproportionately higher demand for wood-based cellulosic fibres in the coming years (Haemmerle 2011) and thus, increase the share of lignocellulosic fibres in the total fibre mix. This development is already mirrored in an increasing global production of dissolving pulp from 3.42 Mt. to 8.37 Mt. between 2008 and 2018 (FAOStat 2020). Since the global production of mechanical and chemical pulp remained fairly constant over this period, the increasing amount of dissolving pulp production increased its share in total wood production from nearly 1.8% to 4.5%. (FAOStat 2020). In this period, the total increase in global dissolving pulp production equals an overall growth of 145% and an annual increase of approximately 9% (FAOStat 2020). If production and consumption of dissolving pulp would stick to these growth patterns, the annual production of dissolving pulp could exceed 25 Mt. after 2030.

Taking into account the growing economic importance of lignocellulosic products, their inclusion in wood products market analysis seems to be essential. Research on traditional forest and wood-based markets is prevalent, well-institutionalized and frequently updated. Wood processing sectors and pulp and paper industries have been well researched from macro and micro perspectives. Important economic parameters including supply and demand elasticities have been (re-) estimated many times (e.g., Buongiorno 1978; Turner and Buongiorno 2004; Brown and Daowei, 2005; Michinaka et al. 2011; Buongiorno 2015; Rougieux and Damette 2018; Morland et al. 2018; Buongiorno 2019). However, no attention has been paid thus far to the macroeconomic relations of formerly niche but now emerging products made from lignocellulose-based materials like dissolving pulp or cellulose-based chemical derivatives or textile fibres. To our knowledge, these products have not yet been addressed in global wood products market analysis. Hence, key economic parameters such as demand or supply elasticities of lignocellulose-based products are not available. Following Hetemäki and Hurmekoski (2016) and Morland et al. (2018), market elasticities are one of the most important parameters of change and a prerequisite for the understanding of macroeconomic relationships. Robust market elasticity estimates can reduce uncertainty and thus improve market-modelling and policy analysis (Buongiorno and Johnston 2018).3

Taking into account the growing economic importance of lignocellose-based products, the aim of the present work is to study how major economic drivers influence the economic development of lignocellulose-based products. For this purpose, we study income and price effects on import and exports volumes in form of elasticities from import and export functions. Hence, this study uses price and income variables as unified and conventional set of explanatory variables. We estimate the effect of changes in global real product prices and income (GDP) on the development of import demand and export supply of “Dissolving Pulp”, “Cellulose and its Chemical Derivatives in its primary form” (hereafter chemical derivatives), and “Cellulose based Textile Fibres in its primary form” (hereafter textile fibres). In addition, we estimate the effect of changing income and price levels on apparent consumption volumes of "Dissolving Pulp". With these estimations of price and income elasticities, we provide key information for the adaptation of forest product market analysis to the growing bioeconomy. Thus, the elasticities estimated in this work can be used for the enhancement of mathematical equilibrium models which consider the global forest products market, such as the GFPM (Buongiorno et al. 2003) and the EFI-GTM (Kallio et al. 2004). As models of this kind simulate future market developments and interdependencies, they are basic tools for the analysis of, e.g., policy implications. In order to enhance projections and inferences drawn from global forest products market modelling, the inclusion of emerging lignocellulosic products and their market elasticities into the model framework seems inevitable.

In the following section, we will describe the economic approach as well as the product data, its categorization, and sources. We will further explain data particularities, the handling of panel data and introduce the econometric methods. Section 3 describes and discusses our results, and Section 4 concludes this paper.

3.3. Methods

This study build on aggregated country data including supply and demand volumes, real prices as well as real income (GDP). Due to the limited availability of data on the domestic supply and demand of lignocellulose-based chemical derivatives and textile fibres, our analysis focuses on demand and supply patterns in international markets represented by import demand and export supply, respectively. We choose an econometric approach and use panel data regression models for the estimation of import demand and export supply equations with price and income (GDP) effects in the form of Q = f(P, GDP). The estimated econometric models provide import demand and export supply elasticities with GDP and prices as explanatory variables. In addition, data of dissolving pulp allow for the calculation of apparent consumption (i.e., production plus import minus export) and thus, for the estimation of price and income (GDP) elasticities for apparent consumption.

In line with basic economic theory of demand models, we expect the signs of our explanatory variables in import demand and apparent consumption models to be negatively related to changes in price and positively correlated to changes in income (GDP): with increasing income the import demand for lignocellulose based products is expected to increase, and the income elasticity of import demand is, therefore, positive. With increasing prices, the import demand is expected to decrease since consumers receive a lower quantity of a certain product for the same expenditure level. Thus, the price elasticity of demand is therefore, negative. Since the development of the dissolving pulp industry, e.g., depends on a substantial amount of capital input, technical resources, and expertise (Bonnefoi and Buongiorno 1990), we expect the export elasticity of income to be positive. The price elasticity of export supply could be positive or negative. Traditionally the domestic price elasticity of supply for normal goods is expected be positive since, in the theory of supply for normal goods– at least national markets - supply increases when the price increases. However, international price elasticities of supply could also be negative in an international price-competitive environment (Raissi and Tulin 2015) where multiple supply countries have the role of polypolic pricetakers (Bayar 2018). In such an environment, increasing prices lead to decreasing supply due to decreasing demand because buyers switch to other fibre resources or more competitive suppliers. Signs opposite to our expectations could be due to several reasons (which are by no means exhaustive). If, e.g., the demand for a certain product decreases with an increasing income we might have to deal with an inferior Giffen good while a decreasing export supply with increasing prices may point out that export supply is governed by (international) demand in export markets (Jonsson 2012).

We use our results from dissolving pulp models to discuss whether import demand elasticities are a suitable substitute for elasticities of apparent consumption. For this, we statistically compare import and apparent consumption elasticities of dissolving pulp and test, whether import elasticities could be a suitable proxy and substitute for apparent consumption elasticities.

3.3.1. Products and Data

3.3.1.1. Products

Dissolving Pulp – also known as dissolving cellulose - is listed in the forest products statistic of the FAO (FAOStat) in the category of wood pulp as "chemical pulp of dissolving grades made from coniferous or non-coniferous wood using sulphate, sulphite or soda processes" under the Code 1667 (FAOStat 2019a).1 Dissolving pulp is a uniform product with a high grade of alpha-cellulose (>90%) and a low content of hemicellulose, lignin, and resin (FAOStat 2019a; Bajpai 2014). It is mainly a raw material for the production of cellulose-based derivatives and regenerates. Cellulose-based chemical derivatives are used, e.g., in cellulose plastic materials and lacquers, whereas cellulose regenerates are mainly used for man-made fibre production (FAOStat 2019a; Bajpai 2009). At present, the major share of global dissolving pulp is used in textile industries for the production of viscose rayon and other fibres (own calculations based on the The Fibre Year (2019)).

"Cellulose and its chemical derivatives in its primary form" is a product aggregate listed by the UN Comtrade database (UN Comtrade 2018) under the global Harmonized System (HS), Code Chapter 39 (plastics and articles thereof) and the heading Code 3912 (cellulose, chemical derivatives in its primary form). It includes cellulose acetates plasticized and non- plasticized, cellulose nitrates, carboxymethylcellulose, cellulose ethers and other cellulose derivatives, all in their primary forms. Common products made of chemical derivatives are: paints, binders, glues, artificial leather, cigarette filters, and various commodities manufactured by the food, pharma, and cosmetic industries. In these sectors, cellulose-based chemical derivatives can substitute input materials such as polyethylene and polypropylene, natural and synthetic fibres and plastics.

Man-made cellulose-based textile fibres use cellulose (mainly from wood fibres) as a raw material. They originated in the middle of the 19th century as the first man-made fibre was developed and applied in textile industries (Chen 2015). Unlike chemical derivatives, cellulose-based textile fibres are not listed as an official product aggregate in the UN Comtrade (2018) classification system. To create this product aggregate, we compiled information from several different products listed in the UN Comtrade database under the global Harmonized System (HS) Code Chapter 54 (man-made filaments) and Chapter 55 (man-made staple fibres). The sub-heading codes used are 5403 (artificial filament yarn, not retail) and 5504 (artificial staple fibres), which include different types of cellulose acetate, viscose rayon yarns, and staple fibres. Viscose is an important substitute for, e.g., cotton, whereas lyocell and acetate, as high-quality fibres are substitutes for, e.g., polyester fleece and silk. The detailed decoding and nomenclature of the product aggregates used for the present study is given in Table 3.4 (in annex).

3.3.1.2. Data Sources

Our main sources for data and supplementary information are the United Nations FAO Statistical Database (FAOStat 2018), the UN International Trade Statistical Database (UN Comtrade 2018), and the World Bank Database (World Bank 2019; World Bank, 2019b). These databases provide country-specific information on the global scale: FAOStat provides yearly, quantitative data on country production, import and export volumes of forest-based products plus total trade value of imports and exports. The UN Comtrade international trade statistics data base (referred to as UN Comtrade) provides official, detailed data on countries' international trade flows for nearly 100 commodity chapters organized according to the harmonized commodity description and coding system (HS). In a given year the data reports include import, re-imports, export and re-export quantities and values. The World Bank's World Development Indicators (WDI) provide country data on GDP developments and GDP deflator rates on the global scale. We state country-specific GDP values in constant 2010 US$ using data from the World Bank (2019b) Development Indicators database (indicator: NY.GDP.MKTP.KD).

For the purpose of the present study, we calculate apparent consumption and unit values (price per ton) from data on production and trade as follows: we calculate apparent consumption of dissolving pulp based on reports from FAOStat (2018) as domestic production plus imports minus exports for each country in a given year. Import and export unit values of dissolving pulp, chemical derivatives and textile fibres are the total import or export value of a given product in a given country and year divided by the total import and export volume of said product in a given country and year as given in (FAOStat, 2018) and (UN Comtrade, 2018). In addition, we calculate the domestic price of dissolving pulp in a given country and year as the weighted average of import and export quantities in total trade volume:

$$P_{b,i,j} = \frac{eV_{b,i,j} + iV_{b,i,j}}{(eQ_{b,i,j} + iQ_{b,i,j})} \qquad [27]$$

Where $P_{b,i,j}$ is the price of a product *b* in a country *i* and year *j*, *eQ* and *iQ* the import and export quantity, and *eV* and *iV* the import value, respectively.

All prices are converted to real prices stated in 2010 US$. We use the linked GDP deflator series (indicator: NY.GDP.GEFL.ZS.AD) from the World Development Indicators database (World Bank 2019), which allows for the comparison of values across periods.

3.3.1.3. Panel Data

The use of panel data can improve the inference made with regard to both dynamics of change and model parameters, and, by doing so, improves the reliability, precision and efficiency of the estimations whereas the improvement in the estimations relies on the inference of the behavior of one entity based on the behavior of others (Verbeek 2012; Baltagi 2005; Hsiao, 2014).

The present study uses unbalanced panels from country reports with individual cross sectional “country” (i) and time “year” (t) observations. Depending on the product and time period, scattered data reports include a varying number of countries (n = 1, …, 27 ≤ n ≤ 180) and a varying amount of cross sectional observations (i = 1, …, 101 ≤

N ≤ 2196), and two different time series length (t = 1, …, 8 ≤ T ≤ 16). Following the classification of Baltagi (2005), this study builds on different sets of micro panels; each panel data set consists of a considerably large number of country reports over a considerably small number of years T < < N (see Table 3.6 in annex). To prevent biased modelling results due to messy incoming data, we clean and reduce information from the data bases. For details, please refer to the text given in the Annex (chapter 3.7.1).

3.3.1.4. Input Data Constancy and Time Series Cuts

Input data stationarity is an important issue for consistent model parameter estimates (Rougieux and Damette 2018). Especially problems inherent to the use of time series lines that span over changing eras of trends must be considered (Pritchett 1987; Hetemäki and Hurmekoski 2016).

Following the conclusions of Hetemäki and Hurmekoski (2016) and Buongiorno (2015), we assume that econometric model estimations for forest products, that use continuous data from 1992 to 2015, could be biased by structural changes. Whether these estimations build on previous developments or on trends taking off after the turn of the millennium, is decisive for the estimation results. Therefore, we test times series of all input data for parameter stability before we run the estimation procedure for elasticities. We statistically analyze whether explanatory parameters stay constant across cross-sectional units (i) and years (t) or if the parameter undergoes a shift during an estimation period and thus, potentially introduce instability (Pritchett 1987). For this purpose, we test time series input data for structural changes and constancy using a change-pointer estimator, the MOSUM test. The MOSUM test is a test based on moving sums of residuals (for a methodological overview see Chu et al. 1995).The test refers to the null hypothesis that the input data parameter mean is constant over time and that the time series is explained by a constant parameter plus noise. We use this null hypothesis to test whether our input data are subject to structural changes between 1992 and 2015 with a significance level of 0.05. Since we observe structural changes, we use the test in a second step to iteratively detect and statistically define sub-periods with a stable input data parameter mean. For this purpose, we start with the base year 1992 and then subsequently add year by year until the null hypothesis of parameter constancy needs to be rejected for a certain time series. Then, we start with the first year of the second and third period, respectively, by replicating the procedure. By doing so, our condition was to create data subsets of the same time length for all products as well as import, export and apparent consumption models. We subsequently run the models for elasticity estimation for each of the sub-periods (see chapter 3.4.1). For statistical MOSUM analysis, we use R 3.4.3 and the strucchange (Zeileis et al. 2002) package. The MOSUM test computes an empirical fluctuation process of sums of residuals in linear regression models based on a generalized fluctuation framework and includes the test on moving sum estimates (MOSUM) on OLS residuals (Zeileis 2006). The full R code on testing fluctuation in time series input data can be found in the supplementary materials to this study. Additionally, we show the significant influence of periods in an aggregated model with dummy variables in Table 3.5 (see annex).

3.3.2. Econometric Model Specification and Testing

We estimate income (GDP) and price elasticities of dissolving pulp, cellulose-based chemical derivatives and textile fibres for import demand, export supply, and apparent consumption (the latter only for dissolving pulp). The special focus of this approach is to provide elasticities for their application and incorporation in economic partial equilibrium models for the forest products market. The basic methodological approach chosen, slightly modified, has been applied in previous studies carried out for the estimation of price and income elasticities including the recent studies of Turner and Buongiorno (2004), Michinaka et al. (2011), Rougieux and Damette (2018), and Morland et al. (2018).

3.3.2.1. Econometric Panel Data Models

We use econometric panel data regression models to analyze the effects of changes in real GDP and real prices on import demand and export supply volumes of dissolving pulp, cellulose based derivatives and textile fibres as well as on apparent consumption volumes of dissolving pulp. For this purpose we use the elasticity approach based on single equation models to study the price and income effects in volumes flows. Thus, import, export and apparent consumption volumes are regressed on income (GDP) and real import, export, and domestic prices, respectively.

The basic method to fit statistical models is the ordinary least squares (OLS) model (e.g., Hayes and Cai 2007). The standard linear model for pooled panel data can be written as:

$$y_{it} = \alpha + \beta x'_{it} + u_{it} \qquad [28]$$

$$u_{it} = \eta_i + v_{it} \qquad [29]$$

Where y_{it} is the depended outcome variable representing import demand and export supply volumes, $i = 1, \dots, n$ is the country index, $t = 1, \dots, T$ the time index, x_{it} the matrix of independent variables representing a given country in a given point in time, α the constant intercept, β the slope coefficients, and u_{it} an uncorrelated random error term with zero mean and constant variance σ_{u^2}. The latter assumption requires that the error term is neither serially correlated nor heteroskedastic. We consider u_{it} to be composed of the components $\eta + v$. The first component η represents the unobservable individuals' heterogeneity thought to be constant over time, whereas

v represents the usual remainder disturbance term (idiosyncratic error) changing over time and individuals. Since we aim at estimating market elasticities, we build on the equation:

$$y_{it} = \alpha * P_{it}^{\beta_1} * GDP_{it}^{\beta_2} * u_{it} \tag{30}$$

The logarithmic transformation of the function is used to obtain a log-linear functional form of the standard linear model in order to directly derive elasticities from the model coefficient estimates. Applying the logarithm yields the estimation equation:

$$log\, y_{it} = \alpha + \beta_1\, log\, P_{it} + \beta_2\, log\, GDP_{it} + u_{it} \tag{31}$$

Depending on the assumptions regarding exogeneity, and whether the components of the error term are country specific or random, the type of the analytic regression model employed for parameter estimation could differ. Therefore, we consider three types of linear regression models: a constant coefficient (pooling) model, a random effects model (RE) and two fixed effects models, one using a within estimator (FE) and one using a first-difference estimator (FD). Statistics for the estimation of linear panel models are carried out using the R 3.4.3 and the plm (Croissant and Millo 2008) package. The package is suitable for unbalanced panel data and the estimation of pooled OLS (pooling), random effects (RE), and fixed effects (FE) and first–differences (FD) models.

The pooled OLS model is a suitable estimation method as long as the individual component of the error term is missing. If the individual error term η exists and is correlated with the explanatory variables x, the within-transformation of the FE estimator eliminates the unobserved individual heterogeneity effect η by demeaning (eliminates the deviation from individual means by subtracting the group mean from the variables) the data (Verbeek, 2012). In the FE model, the intercept is different for the individual units whereas the regressors are independent of the usual remainder disturbance term v thus being strictly exogenous.

The first difference estimator FD is another possibility to eliminate the time-invariant individual heterogeneity component η by first-differentiating the equation with pooled data, and thus addressing issues of serial correlation by subtracting the lagged observations. In addition, this estimator does not require the strict exogeneity of the regressors but allows for, e.g., correlation between x_{it} and u_{it-2} (Verbeek, 2012). If the usual remainder disturbance term v is correlated to ηi and is uncorrelated with the explanatory variables, RE is a suitable estimation method. We use a RE estimation method with feasible generalized least squares. We choose the *swar-estimators* (Swamy and Arora, 1972) for the estimation of the random effects model in the *plm* (Croissant and Millo, 2008) package. The full R code for data processing, visualization, model estimation and the calculation of robust standard errors is given in the supplementary materials to this study (available at https://www.sciencedirect.com/science/article/abs/pii/S1389934121000289?via%3Dihub).

3.3.2.2. Statistical diagnostic test for model specification

To provide reliable conclusions from the application of econometric models, we apply a consecutive series of model specification and misspecification tests. Based on test results, we choose the model type considered as suitable to deliver robust parameter estimates. For this purpose, we use the following different types of test:

First, data can be pooled if the basic assumption of homogeneity of slope coefficients holds (Verbeek 2012) whereas parameter heterogeneity among (cross-sectional) individual intercepts or slopes over time leads to bias and false inference (Hsiao, 2014). To test the applicability of a pooled OLS model, we test the poolability of data using the F statistic of poolability with the null hypothesis that individual coefficients are the same for all individuals. Further, we apply the Breusch-Pagan Lagrange Multiplier Test in order to check the null hypothesis of zero individual, time, or two ways effects in the panels and so, to use pooled OLS.

Second, homoscedasticity is a central assumption in standard linear regression (Hayes and Cai 2007). The ordinary least squares (OLS) model relies on the essential assumptions that (i) the usual error disturbance term v is homoskedastic, i.e., it has a constant variance across all cross sectional units and time periods (Hayes and Cai 2007; Baltagi 2005) and (ii) errors are not correlated with each other (Verbeek 2012). Heteroscedasticity or autocorrelation occur if the usual error terms are not identically or independently distributed, and thus, the essential assumptions do not hold (Verbeek 2012). Fitting a linear OLS regression model to heteroskedastic data or data serially correlated with the usual error disturbance term v will still yield consistent, unbiased coefficient estimates. However, these coefficients estimates may no longer be efficient and the validity of the statistical test is affected because the computation of standard errors (t- and F-tests) could be biased (Verbeek 2012; Hayes and Cai 2007; Baltagi 2005). Against this background, we test the model error structure for homoscedasticity using the Studentized Breusch Pagan Test to for heteroscedasticity with the null hypothesis that the variance of the residuals of the regressors are not significantly different and thus, are homoscedastic.

Third, another fundamental issue for model specification is whether the random component shows a random or fixed effect. In particular, if the time dimension T is small, the coefficient estimates obtained with different model types can be substantially different (Verbeek 2012; Hsiao, 2014). To decide whether to use a fixed or random effects model, we apply the Hausman Test for model misspecification (Hausman 1978) to test the null hypothesis that both the random effect estimator and the fixed effect estimator are consistent, i.e., that the random error component is random and uncorrelated with the regressor xi (Hsiao, 2014).

Fourth, it is possible that the usual error terms of a specific cross-sectional unit is serially correlated (Verbeek 2012). As it is the case for heteroscedasticity, the presence of serial correlation in the usual error disturbance term v does not affect the consistency of coefficient estimates but leads to the estimation of inefficient coefficients and biased standard errors (Verbeek 2012; Baltagi 2005). Thus, we test the null hypothesis of zero correlation between the residuals of the same group using the Wooldridge's test for unobserved effects, which would arise from a systematic variation of unobserved individuals over time and be expressed by serially correlated errors in the model (Hsiao, 2014). In addition, we apply the Wooldridge's test for serial correlation in residuals of fixed effects panel models with the null hypothesis of no autocorrelation. Based on the results of this test, we decide whether to use the fixed effect estimator or the first-difference estimator.

To assess the empirical power of different econometric models while reducing effects from possible heteroscedasticity on the inferences, we follow the suggestions of Hayes and Cai (2007) and Baltagi (2005) and calculate heteroskedastic robust (HC) standard error. We compute heteroscedasticity robust standard errors, t statistics and p-values for all estimated coefficients. For statistics, we use R 3.4.3, the *lmtest* (Zeileis and Hothorn 2002) and the *sandwich* (Zeileis 2004) packages. For the estimation of robust covariance matrix of parameters, we choose the *HC3* approach derived from Arellano (1987). The HC3 procedure is considered to work well for smaller cross sectional panels regardless of the presence or absence of heteroscedasticity. Long and Ervin (2000) state that *"…there is only a slight loss of power associated with HC3, when the errors are indeed homoscedastic"*. Further, both Cribari-Neto et al. (2005) and Hayes and Cai (2007) confirm that among the HC test types, the HC3 procedure tends to be superior compared to other types. The full R of the testing procedure is available in the supplementary materials given to this study.

3.3.2.3. Testing the substitutability of regression coefficient estimates

We expect to observe similar effects in import demand and apparent consumption model estimations. Thus, we assume that the regression coefficients of these models are comparable and thus, interchangeable. In other words, we suggest that these coefficients could be used as substitutes for further application in, e.g., mathematical market models for the wood products market. To test this hypothesis, we analyze the differences between the two regression coefficients in dissolving pulp models. We compute a function based on the work of Paternoster et al. (1998) and apply this function to compare the coefficient estimates from the model estimations obtained for import demand and apparent consumption of dissolving pulp. The test refers to a general z-test. It statistically explores the differences between two coefficients and the estimated standard error of the difference. The test bases on the null hypothesis that the difference between the coefficients of the first and the second model is non-significant. It is derived from the formula:

$$Z = \frac{(y_1 - y_2)}{\sqrt{SD_1^2 - SD_2^2}} \qquad [32]$$

Where Z is the difference in estimates, y_1 and y_2 coefficient estimates and SD_1 and SD_2 is the standard deviation, respectively (Paternoster et al. 1998). Note that only coefficient estimates computed with the same estimation method are comparable to each other. As mentioned in chapter 3.3, we only have available data on net domestic consumption of dissolving pulp. This allows us to estimate the respective elasticities solely for dissolving pulp. For the other two product categories (cellulose based chemical derivatives and textile fibres) we must, therefore, assume that price and income changes also affect both import demand and net domestic consumption in a similar manner.

3.4. Results and Discussion

The results of any econometric analysis depends on the availability, reliability, and coherency of data. The advantage of the chosen emerging lignocellulosic products is that they are traditional niche products with a long data history of aggregate data for volume and price variables. However, the precision of econometric parameter estimates and, in particular, the precision of market elasticities estimates, are the prerequisite for their reasonable use in mathematical market models. Thus, we undertake several steps to improve the precision of our parameter estimates.

3.4.1. Input data constancy and time series cuts

We pool scattered country data over time to obtain a maximal amount of data. Further we test and choose the optimal length of the time series to determine structural breaks and their influence on present and future market developments (Hetemäki and Hurmekoski 2016) since *"…both income and price elasticities are affected by structural changes and policy actions (Pritchett 1987, 1)"*. We use time series cuts to overcome this challenge. The results from the OLS-based MOSUM test vary for the three different products and their input data on GDP and prices, as well as on the import demand, apparent consumption and export supply volumes.

For all GDP time series, except for textile fibres, the OLS-based MOSUM test does not reject the null hypothesis that the entire time series from 1992 to 2015 can be explained by a constant mean plus noise ($\alpha < 0.05$). On the contrary, the null hypothesis of parameter constancy is strongly rejected for all price data time series across all products, except for textile fibres exports from 1992 to 2015. Referring to data on import demand, apparent consumption and export supply volumes, the findings vary from product to product. The null hypothesis of a constant mean was not rejected for the import demand and export supply volumes of cellulose based chemical derivatives, as well as for import demand and apparent consumption of dissolving pulp, at least on $\alpha < 0.05$. The null hypothesis was, however, strongly rejected for dissolving pulp export supply as well as for import demand and export supply of cellulose based textile fibres.

These findings point to structural changes in historic input data. To cope with these structural changes, we split time series into subsets. We use the OLS-based MOSUM test as a detector tool and iteratively delimit three periods of equal time length and with constant parameter means (see chapter 3.3.1.4). We want to run the elasticity estimations across different product dimensions for sub periods of the same time length. Thus, the statistical difference of the sub periods in one product group lead to and legitimate the cut of the others. As a result, we obtain three eight-year periods: 1992–1999; 2000–2007; 2008–2015. For these periods, the null hypothesis of constant means is not rejected for all parameters on $\alpha < 0.05$, except for GDP and import volumes of textile fibres from 1992 to 1999.

It seems that the global market pattern of the lignocellulosic sub-sector is strongly related to global macroeconomic events. Statistically, this market pattern change with, e.g., the collapse of the Soviet Union 1991, with the global recession in 2000–2001 and with the subprime crisis in 2007–2008.

In addition to the three eight-year- periods, we delimit a fourth and longer period (2000–2015) that spans the timeframe after 2000 and for which the null hypothesis of constant mean is not rejected for import demand, apparent consumption, export supply volumes, and GDP time series across all product parameters. However, in this longer period price data of dissolving pulp and textile fibres are characterized by structural changes. We also want to note that it was not possible to create a subset of data reaching from 1992 to 2015, mainly due to structural changes in price data before and after 2000. On the other hand, the results show that the years around the global economic crisis of 2007–2008 could be integrated into the subsets. We summarize test results and periods in Table 3.1.

We show the significant influence of the sub-periods based on the estimation of an aggregated model which includes, in addition to GDP and price variables, these three sub periods as dummy variables. The results are given in Table 3.5 (see annex).

After cutting these three product time series into different sub-sets, we obtain 28 sets of longitudinal panel data3 from three different products. The length of time series ($T = 1, \ldots, 8 \leq T \leq 16$) and the number of cross sectional observations ($N = 1, \ldots, 101 \leq N \leq 2196$) obtained from a varying number of countries ($n = 1, \ldots, 27 \leq n \leq 180$) differ across the panel data sets. We give an overview on main characteristics of data sets in Table 3.6 (in annex).

Table 3.1 Results from parameter constancy tests with OLS-based MOSUM (H0: parameter constancy)

			1992-1999	2000-2007	2008-2015	2000-2015
Dissolving Pulp	import demand	vol	0.15	0.24	0.50	0.05
		price	0.18	0.16	0.15	<0.01
		gdp	0.39	0.51	0.25	0.37
	export supply	vol	0.21	0.40	0.45	0.33
		price	0.33	0.41	0.20	<0.01
		gdp	0.53	0.71	0.61	0.61
	net dom. consum.	vol	0.25	0.32	0.43	0.05
		price	0.12	0.15	0.08	<0.01
		gdp	0.39	0.51	0.25	0.37
Chemical Derivatives	import demand	vol	0.49	0.47	0.32	0.12
		price	0.19	0.25	0.33	0.07
		gdp	0.23	0.47	0.52	0.26
	export supply	vol	0.28	0.60	0.40	0.33
		price	0.08	0.38	0.58	0.06
		gdp	0.06	0.55	0.56	0.39
Textile Fibres	Import demand	vol	<0.01	0.32	0.26	0.17
		price	0.17	0.25	0.27	0.03
		gdp	<0.01	0.27	0.17	<0.01
	export supply	vol	0.48	0.42	0.24	0.11
		price	0.52	0.29	0.46	0.03
		gdp	0.49	0.51	0.49	0.20

Note: The delimitation of periods with constant parameter mean is the result of an iterative testing procedure. Consumption is the apparent consumption calculated as domestic production plus imports minus exports, vol is the product quantity traded or consumed in a given year (t), price is the unit price of the traded or consumed product (US$) in a given year (t), and GDP is the real gross domestic income (US$) of a given country in a given year (t).

The structures of the different data sets show remarkable similarities and differences. First, data of dissolving pulp import demand and apparent consumption are nearly congruent with each other in terms of the number of country reports and the number of observations made over time. In contrast, data on dissolving pulp export supply are considerably fewer due to a lower number of exporting countries and their related observations. Records from the FAOStat (2019b) database prove that the production and export supply of dissolving pulp is concentrated in a few countries in the world whereas the import demand is more widespread (see Figure 3.2). The analysis of the textile fibres sector draws a similar picture: the number of importing countries exceeded the number of exporting countries between 50% and 60% (depending on the period) whereas the number of import records is nearly twice the number of export records. For cellulose based chemical derivatives, the number of importing countries and records also exceeds the number of exporting countries and records, but the ratio is more balanced compared to that of the cellulose based textile fibre sector (see Figure 3.2).

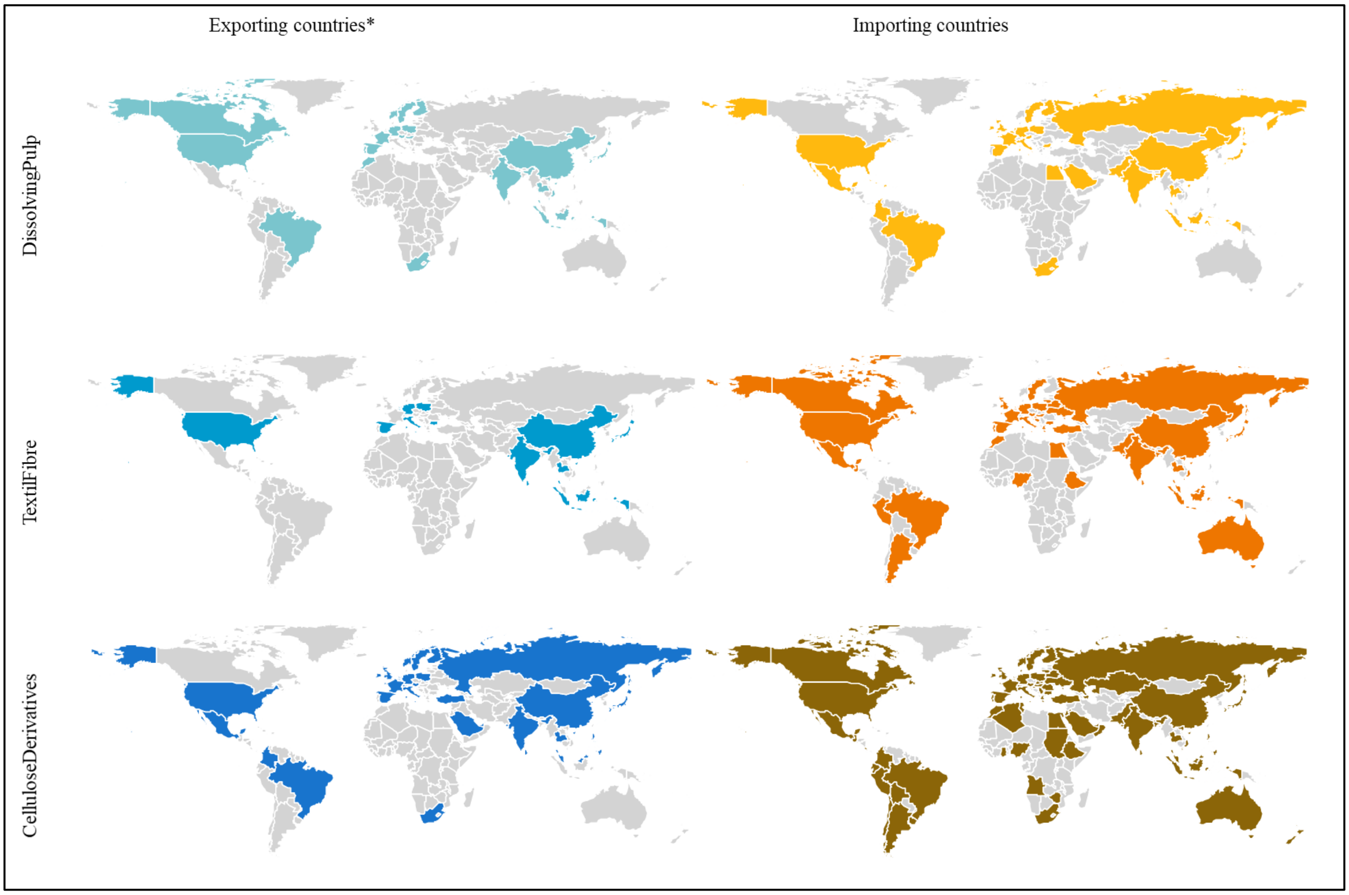

Figure 3.2 Global export supply and import demand of dissolving pulp*, cellulose based textile fibres, and chemical derivatives.

Note: This Figure refers to country reports in the years 2015 / 2016. It considers countries with production or trade volumes > 1,000 t per year and excludes countries with lower commodity flows. Countries with export supply are represented on the left hand side and countries with import demand on the right hand side of the figure. Export supply is the quantity of a certain good delivered by a country to the global market whereas import demand is the quantity of a certain good imported by a country from the global market. *Comprises countries with both dissolving pulp production and export supply; export countries without domestic production are Belgium and Germany. Data: FAOStat 2019b, UN Comtrade 2018 (cleared, according to chapter 3.7.1).

Our analysis on the traded volumes of cellulose based chemical derivatives and textile fibres shows some particularities: according to data from the UN Comtrade database (2018, cleared according to chapter 3.7.1) the trade volume in the cellulose based chemical derivatives sector exceeds the trade volume of textile fibres. However, since our calculations are based on reports from The Fibre Year (2018) and FAOStat, (2019b), we assume that the global production volume of cellulose based chemical derivatives is only a fraction of the global cellulose based textile fibre production. In recent years, the global production of cellulose-based textile fibres exceeds six million tons, and thus gives evidence that the major share of global dissolving pulp is used for the textile fibres production (again, our calculations are based on reports from The Fibre Year (2018) and FAOStat (2019b)). Figure 3.2 underlines the former considerations.

3.4.2. Statistical Diagnostic for Model Specification

Since issues like heterogeneity, heteroscedasticity, multi-collinearity, and serial correlation can affect the reliability of model estimates, we use a set of tests for the statistical diagnostic of input data characteristics. Based on the test results, we specified the appropriate model for parameter estimation. We summarize the statistical diagnostic and model specification results in Table 3.6 (in annex).

In regard to the input data of dissolving pulp import demand and apparent consumption for the period from 1992 to 1999, the F-statistic test for poolability strongly does not reject the null hypothesis of parameter stability. At the same time, the Lagrange Multiplier tests for individual, time, and two-ways effects for unbalanced panels do not reject the null hypothesis of no effects. In addition, the Studentized Breusch-Pagan test does not reject the null hypothesis and the condition of homoscedasticity (homogeneity of variance). Thus, for these two data sets, a simple pooled OLS regression model estimator is most likely consistent and efficient. In this case, we select the estimates computed with the pooling model as suitable elasticities. The same holds for input data of dissolving pulp import demand for the period from 2008 to 2015. However, for the same period, data of dissolving pulp apparent consumption not only passed the Studentized Breusch-Pagan for heteroscedasticity, on $\alpha < 0.05$, but also the Wooldridge's test for unobserved effects (autocorrelation of residuals); following these results, the Wooldridge's test for serial correlation in FE panels is not rejected. Hence, we decide to stand back from the OLS model and select the estimations of the FD model as suitable elasticities in this special case. Looking on data of dissolving pulp import demand and apparent consumption for the period from 2000 to 2007 and from 2000 to 2015, the results of F-statistics do not reject the null hypothesis of stable coefficients. Likewise, the Lagrange Multiplier tests for individual, time and two-ways effects (Breusch-Pagan) for unbalanced panels do not reject the null hypothesis of no effects. However, the results of the Studentized Breusch-Pagan Test reject the null hypothesis of homoscedasticity pointing to heteroscedasticity of variances. Yet the Hausman Test indicates that the error components are not correlated with the explanatory variables and thus can be taken as random. Hence, the random effect estimator is consider to deliver both consistent and efficient results for these periods. We, therefore, select the elasticities estimated with the RE model. For dissolving pulp export supply, the results lightly differ: the testing procedure shows that the pooling model would provide an appropriate estimator for the periods from 1992 to 1999 and from 2000 to 2007, whereas for the periods from 2008 to 2015 and from 2000 to 2015 the random effects model would provide the appropriate estimator.

Regarding the input data for chemical derivatives export supply, the same testing procedure shows that the random effects model turns out to be the appropriate for the periods from 1992 to 1999 and from 2000 to 2015 whereas the OLS pooling model would be the appropriate estimation model for the periods from 2000 to 2007 and from 2008 to 2015, respectively. Concerning chemical derivatives import demand, the random effects estimator was chosen as appropriate for the periods from 1992 to 1999 and 2000 to 2007. However, for the periods from 2000 to 2015 and 2008 to 2015, the Hausman Test strongly rejects the null hypothesis that both the fixed and the random effect estimators deliver consistent results and thus a fixed effects model is suggested. Wooldridge's test for serial correlation in residuals of fixed effects panels does not reject the null hypothesis of no serial correlation in the residuals; we, therefore, use the fixed effects within instead of the first differences estimator.

In reference to data on textile fibres import demand, the Studentized Breusch-Pagan test proves our observation of heteroscedastic structures in all periods under consideration at the same time as the Hausman Test rejects randomness in observed effects. Thus, the random effect estimator may deliver inconsistent coefficients, and thus, the use of fixed effects must be assumed. As the Wooldridge's test for serial correlation in FE panels is rejected in all cases, we, therefore, select the fixed effects within estimator as the appropriate method for all four cases. Finally, we estimate all four export supply models of textile fibres with a random effects model.

From these findings we see that heteroscedasticity is an issue in the majority of our data sets across products and time periods. However, in 14 of these cases, the Hausman Test indicates that the error components are random and uncorrelated with the regressors and thus that the random effects estimator is the appropriate estimation method. We also found that the OLS is mainly the best method for the estimation of dissolving pulp and, in some cases, for the estimation of chemical derivatives export supply models. Fixed effects were found in import models of chemical derivatives and textile fibres whereas the first difference estimator is applied once in a model of apparent consumption of dissolving pulp.

3.4.3. Elasticity coefficient estimates

We estimate income (GDP) and price elasticities of dissolving pulp, chemical derivatives, and textile fibres import demand, export supply, and apparent consumption (the latter only for dissolving pulp) from 28 different sets of panel data. The following results show how products' import demand, apparent consumption, and export supply respond to changes in main economic drivers and whether their response patterns fit theoretical expectations or show particularities. In Table 3.2, we present an overview of market elasticity estimates. The respective model estimation used together with the specification test are given in Table 3.6 (see annex). The complete results obtained for all four different estimation methods (pooling, FE, FD, RD) and for all 28 different panel data sets can be looked up separately for each product in Table 3.8 to Table 3.10 (see annex). Further, these tables state additional information on model fit including error's distribution, and F-statistics.

Table 3.2 Results from the econometric estimations of income and price elasticities from macroeconomic panel data models for different periods and products

Product	Parameters	1992–1999			2000–2007			2008–2015			2000–2015		
					import			demand					
Dissolving pulp	intercept	−22.77	(2.91)	***	−24.72	(3.59)	***	−18.12	(2.43)	***	−16.99	(2.28)	***
	price	**0.04**	(0.49)		**0.47**	(0.55)		**- 1.67**	(0.35)	***	**- 1.53**	(0.29)	***
	income	**1.17**	(0.07)	***	**1.13**	(0.10)	***	**1.40**	(0.09)	***	**1.33**	(0.06)	***
	adj. R^2	0.53			0.41			0.46			0.44		
						export		supply					
	intercept	- 5.72	(7.92)		−14.33	(9.17)		- 6.35	(6.50)		- 8.42	(0.59)	
	price	**- 1.35**	(1.02)		**- 0.87**	(0.75)		**- 2.52**	(0.64)	***	**- 1.93**	(0.64)	**
	income	**0.85**	(0.18)	***	**1.07**	(0.19)	***	**1.19**	(0.16)	***	**1.11**	(0.11)	***
	adj. R^2	0.19			0.24			0.25			0.22		
						net		consumption					
	intercept	−25.57	(3.26)	***	−31.06	(3.44)	***				−19.34	(2.22)	***
	price	**- 0.18**	(0.54)		**0.76**	(0.48)		**- 1.80**	(0.47)	***	**- 1.60**	(0.31)	***
	income	**1.35**	(0.06)	***	**1.30**	(0.09)	***	**1.52**	(0.08)	***	**1.44**	(0.06)	***
	adj. R^2	0.56			0.50			0.45			0.50		
Chemical derivatives						import		demand					
	intercept	- 5.01	(1.82)	**	- 8.36	(1.13)	***						
	price	**- 1.41**	(0.18)	***	**- 1.21**	(0.12)	***	**- 1.08**	(0.15)	***	**- 1.19**	(0.09)	***
	income	**1.23**	(0.03)	***	**1.29**	(0.02)	***	**1.12**	(0.03)	***	**1.26**	(0.02)	***
	adj. R^2	0.81			0.82			0.77			0.80		
						export		supply					
	intercept	−19.45	(1.53)	***	−19.97	(1.13)	***	−18.70	(1.08)	***	−19.71	(0.80)	***
	price	**- 0.87**	(0.15)	***	**- 1.17**	(0.11)	***	**- 1.08**	(0.11)	***	**- 1.10**	(0.08)	***
	income	**1.51**	(0.04)	***	**1.63**	(0.03)	***	**1.56**	(0.04)	***	**1.60**	(0.02)	***
	adj. R^2	0.65			0.67			0.64			0.66		
Textile fibres						import		demand					
	intercept												
	price	**- 1.52**	(0.18)	***	**- 1.02**	(0.18)	***	**- 1.48**	(0.17)	***	**- 1.27**	(0.11)	***
	income	**1.18**	(0.06)	***	**1.22**	(0.05)	***	**1.13**	(0.05)	***	**1.17**	(0.03)	***
	adj. R^2	0.50			0.43			0.33			0.44		
						export		supply					
	intercept	- 1.27	(2.53)		- 4.89	(2.05)	*	- 6.55	(2.96)	*	- 4.73	(1.59)	**
	price	**- 1.79**	(0.20)	***	**- 1.69**	(0.18)	***	**- 1.60**	(0.20)	***	**- 1.70**	(0.12)	***
	income	**1.14**	(0.06)	***	**1.20**	(0.06)	***	**1.21**	(0.08)	***	**1.18**	(0.04)	***
	adj. R^2	0.44			0.43			0.42			0.42		

Note: Net consumption refers to apparent consumption. Elasticity coefficient estimates are in bold, standard deviation in () and levels of significance stated as *** < 0.0001; ** < 0.001; * < 0.01; < 0.05. This is a summarizing table, elasticities are shown for the best model, which is chosen on basis of Table 3.7 (see annex).

For import demand and export supply models of chemical derivatives and textile fibres, the explanatory power of income (GDP) and price coefficient estimates is highly significant across models and periods ($\alpha < 0.00$). For import demand, export supply and apparent consumption of dissolving pulp models, the explanatory power of income (GDP) is also highly significant across all periods ($\alpha < 0.00$). However, price elasticities of dissolving pulp import demand, apparent consumption and export supply models are only statistically significant for recent periods: 2008–2015 ($\alpha < 0.00$) and 2000–2015 ($\alpha < 0.01$). The results from the adj. R2 indicate that the variations of import demand, export supply, and apparent consumption volumes are determined from 19% to 82% by real prices and income (see Table 3.2).

Here, we point out four key findings drawn from the analysis of income and price elasticity estimates. Notably, the income elasticities of export supply and import demand share certain characteristics across the different products groups. First, the net explanatory power of income is given in all cases. Second, both export supply and import demand are positively correlated to changes in income. Third, all income elasticities, except for export supply of dissolving pulp from 1992 to 1999, are greater than one. Thus, international export supply and import demand models respond (slightly) elastic to income changes and increase with rising income. Fourth, we found that both income elasticity of export supply and import demand turn out to be roughly stable and of similar magnitude across periods in the case of chemical derivatives and textile fibres. However, we observe some bigger jumps in the magnitude for dissolving pulp import demand and export supply elasticities.

Looking closer to the estimated price elasticities, we observe four substantial differences in both magnitude and significance of dissolving pulp elasticities. First, price elasticities of dissolving pulp import demand and export supply are not always significant and reversely related to price changes but instead show positive signs. The price elasticities estimated for two recent time periods (2000–2015; 2008–2015) are statistically highly significant and show the expected sign. Second, the price elasticities of dissolving pulp import demand and apparent consumption are lower in comparison with those of export supply, thus making exports even more sensitive than imports to price variations. Third, we find that all price elasticities estimated for the import demand and export supply of chemical derivatives and textile fibres are negatively related to price changes and statistically significant for all periods. Fourth, textile fibres export supply has a relatively high but constant level of price elasticities with coefficient estimates varying from −1.60 to −1.79. In contrast, the price elasticities of textile fibres' import demand varies over the periods. In spite of the jumps, textile fibres import demand has always a lower price elasticity than the export supply of textile fibres. Once again, the export supply responds more elastic to price changes compared to the import demand. One explanation for this behavior might be that in international trade, importer choose the cheapest seller – and thus, the export supply is sensitive to changes in prices.

Drawing upon the idea, that both sign and magnitude of elasticities could be indicators of possible structural market changes (Jonsson 2012), we look for changes in the magnitude and/or the sign of different elasticity coefficient estimates over the time periods. As described above, we found that income elasticities turned out to be rather stable across time periods (see Table 3.2) but we see strong variations in price elasticities. In looking at the result from dissolving pulp models, the price coefficient estimates turn from insignificant to significant between the time periods from 2000 to 2007 and the time period from 2008 to 2015. In the case of dissolving pulp import demand and apparent consumption, the break between 2007 and 2008 also brings along a change from positive to negative signs and jumps greater than one in the coefficient's magnitude. Regarding chemical derivatives export supply, the price elasticity turns from inelastic to elastic after 2000 at the same time as the price elasticities of chemical derivatives export supply and import demand slightly jump by 0.20 points. For textile fibres' import demand, we detect two jumps in price elasticities: from the first time period (1992–1999) to the second time period (2000–2007) the elasticity drops by −0.50 points from elastic to linear-elastic and then jumped again by 0.46 points to elastic again in the next time period (2008–2015). These comparisons demonstrate the different dynamics over time, which become both apparent and manageable due to our application of time series cuts. This finding further supports our approach to analyze data for structural breaks in market developments and subsequently uses subsets of input data for model estimations (see chapter 3.3.1.4 and chapter 3.4.1).

As mentioned before, in the first two estimation periods, dissolving pulp import demand and apparent consumption responded positively to an increase in product price. Even though the results do not pass the significance tests, we had a further look on this unexpected relationship. After excluding a reverse causality problem due to endogeneity (which could have been the reason for the opposite sign of price coefficients) via the inspection of residuals against the explanatory variable “price” (see Figure 3.3 in annex), we assume that other factors, e.g., income or other additional effects, may have overcompensated the price effects.

In comparison to previous studies, which analyze demand elasticities of traditional wood products (e.g., Michinaka et al. 2011; Buongiorno 2015; Rougieux and Damette 2018; Morland et al. 2018; Buongiorno 2019), the demand elasticities for lignocellulose products, as estimated in the present work, tend to be more elastic. An exception is fibreboard demand which – depending on the time period and estimation method – in some studies reaches values near and above 1 for the income elasticity (e.g., income elasticity of domestic fibreboard demand in low income countries (0.94) in Buongiorno (2015); income elasticity of domestic fibreboard demand (1.07) in Morland et al. 2018) and below −1 for the price elasticity (−1.42 in Rougieux and Damette (2018)) and thus, are in the range of our estimates for lignocellulosic products import demand. Fibreboard is the most dynamically growing product group among the traditional wood products (its global production increased from 20 million m3 in 1990 to 118 million m³ in 2015 [FAOSTAT, 2020]). The price sensitive demand elasticities of dynamically growing products like fibreboard and lignocellulosic materials can indicate that these products have a number of close substitutes (see chapter 3.3.1.1). Thus, it is easy to switch to alternative products when the price of the emerging one rises. However, it could also indicate that the strong increase in demand goes along with a simultaneous decrease in marginal costs in production and thus, prices. Morland et al. (2018) estimated both import demand and apparent consumption elasticities for traditional wood products for the time period 1992 to 2015. They found that price and income elasticities of import demand tend to respond more elastic compared to the price and income elasticities of domestic demand for traditional wood products. Contrary to this, we observe the opposite effect in regard to dissolving pulp: here, domestic consumption responds more elastic to changes in income and prices than the import demand do.

In reference to the results on the price and income export elasticities, there are no similar studies on lignocellulosic products for referencing the results of the present study. However, there are reports on aggregated country exports elasticities with similar results in terms of the coefficient signs. Bayar (2018) found in his review that the income effect in export models is mostly positive and thus, an increase in income propel demand for exports. In this manner, Senhadji and Montenegro (1999) and Bahmani-Oskooee and Kara (2005), e.g., estimated negative export price and positive income elasticities for a sample of 75 and 28 countries, respectively. Aydin et al. (2004) and Raissi and Tulin (2015), e.g., provide reports on negative export price elasticities for Turkey and India. On global level, Morland et al. (2018) provide negative export supply elasticities for roundwood products.

3.4.4. Testing for equality of elasticity coefficient estimates

Our analysis shows that only a few countries produce and export dissolving pulp. In contrast, there is a large number of importing countries. The number of consuming and importing countries is, in most of the cases and time periods, nearly congruent (see chapter 3.4.1). This shows that import demand is a substantial component of domestic consumption. Following the approach of Kangas and Baudin (2003), Schwarzbauer (2005), and Jonsson (2012), a countries' total demand can be disaggregated into two components: demand for imported products (import demand) and demand for nationally produced products. Since most of the participants in the dissolving pulp, chemical derivatives, and textile fibres markets are importers, the import demand is in almost all countries an integral part of a countries' total demand. Vice versa, the same holds true for a country's total supply: it can be disaggregated into supply for international markets (export supply) and supply for the domestic market. Since in almost all cases, the producing countries are exporters, too (to serve international demand), export supply is an integral part of a country's total supply, at least in the case of dissolving pulp. The results from our model specification tests (see Table 3.6 in annex) confirm that the data sets of import demand and apparent consumption of dissolving pulp mainly share similar structural patterns in different time periods.

Based on these considerations, we assume that the regression coefficients of import demand and apparent consumption models can be used as substitutes in mathematical wood products market models. To prove this assumption, we test the statistical equality of the two regression coefficients. We apply a function based on the work of Paternoster et al. (1998) to compare the coefficient estimates of import demand and apparent consumption of dissolving pulp. The test is based on the null hypothesis that the difference between the coefficients obtained with the first and the second model is non-significant. Hence, we compute a statistical comparison of the regression coefficients from import demand and apparent consumption models of dissolving pulp (see chapter 3.3.2.3). We find that differences were non-significant across models and time periods (see Table 3.3). Since our test results prove to be statistically non-significant, they show that import demand is, to a significant degree, congruent with apparent consumption and confirms the statistical equality of coefficient estimates. Based on this finding, we conclude that price and income regression coefficients of import demand and apparent consumption are statistically similar and hence, interchangeable. Further, the results indicate that variation between coefficients tend to decrease in recent time periods.

Table 3.3 Results from testing the statistical equality of regression coefficients for dissolving pulp import demand and net domestic consumption for different time periods (H0: no statistical difference)

2000 - 2015	RE	e	std	t-Value	Pr(>|t|)
	price	-0.063	0.396	-0.158	0.875
	GDP	0.113	0.092	12,302	0.219
2008 - 2015	OLS	e	std	t-Value	Pr(>|t|)
	price	-0.225	0.490	-0.459	0.647
	GDP	0.087	0.121	0.722	0.471
2000 - 2007	RE	e	std	t-Value	Pr(>|t|)
	price	0.295	0.791	0.373	0.710
	GDP	0.175	0.133	13,167	0.189
1992 - 1999	OLS	e	std	t-Value	Pr(>|t|)
	price	0.720	0.680	10,592	0.291
	GDP	0.135	0.114	11,837	0.238

Note: RE and OLS are the models used for estimation of import demand and net domestic consumption models of dissolving pulp, e is the similarity coefficient of import demand and net domestic consumption models of dissolving pulp, and std the Standard Error.

Due to the absence of appropriate data, we cannot test this relationship for chemical derivatives and textile fibres. However, our analysis indicates structural similarities between dissolving pulp and chemical derivatives and textile fibres. Based on this finding, we therefore assume a similarity between import demand and domestic consumption which also holds for chemical derivatives and textile fibres and thus appears feasible to use the import demand elasticity estimates in modelling as demand elasticities.

3.5. Conclusion

Within a growing bioeconomy, forest-based products markets will further change and diversify, e.g., due to the increasing substitution of fossil-based materials with lignocellulose-based products in the chemical and textile industries. The expected growing economic importance of these emerging products shows that its inclusion into wood products market analysis necessary. Although the market behavior of traditional wood-based products, such as sawnwoods, panels, and papers, are well researched, little is known about emerging lignocellulose-based products. In particular, research on market elasticities of dissolving pulp, cellulose and its chemical derivatives or cellulose-based textile fibres are not available. To overcome this gap, our paper estimates and tests import demand, export supply, and apparent consumption elasticities with income (GDP) and price effects from global econometric models (the latter only for dissolving pulp). Any econometric study depends upon a meaningful amount of coherent data in terms of cross sectional entities and time series length. Since pertinent data for emerging products are scarce, we build our econometric analysis on traditional niche products (for details see chapter 3.3.1.1). Most importantly, these products possess a sufficiently long and globally institutionalized data reporting history. Our analysis confirms the significant relationship between changes in the real prices and income (GDP) and the relative export supply and import demand volumes. The reported adj. R2 shows that a set of two key explanatory variables could explain a wide extend of effects in import demand, export supply and apparent consumption volumes. From this relationship, we infer that both income (GDP) and real prices are substantial explanatory variables in import demand, export supply and apparent consumption model of dissolving pulp, lignocellulose based chemical derivatives and textile fibres. Our results further reveal that, in particular, the income (GDP) development is a constant model determinant. This finding is in line with Hetemäki and Hurmekoski (2016, 9) who state *that "traditional major drivers of forest products consumption and production, i.e. economic growth (GDP) and population growth, have continued to follow the past pattern globally"*. On the contrary, we find price developments to be more volatile and characterized by structural breaks over time. We further observe that in our earlier estimation time periods (1992–1999; 2000–2007), price equations of dissolving pulp models yield insignificant elasticity estimations and opposite parameter signs. In addition, we find jumps in the magnitude of coefficient estimates between the different estimation periods. Here, our time series cuts enable us to preventinsignificant and fuzzy results and separate out such impacts from contemporary relationships.

We report positive income and negative price elasticities (except for dissolving pulp for the time period from 1992 to 1999 and from 2000 to 2007) for import demand, apparent consumption and export supply models across all products. With this behavior, import demand and apparent consumption models meet theoretical expectations. Since the development of export supply is conversely related to price changes in all estimated models, too, we suggest that the export supply models are sensitive to international price competitiveness (Raissi and Tulin 2015) and thus, represent international demand for exports (Jonsson 2012) rather than domestic export supply: the market demand curves of international consumers have negative slopes. The increasing export price of an individual country implies a higher price of this product in the international market. This leads to decreasing competitiveness and decline of domestic exports supply volumes since international buyers are discouraged from buying the more expensive product (Bayar 2018). Instead, they switch to other suppliers or product substitutes. At the same time, an increase in income positively affects foreign demand for export products (Bayar 2018). The positive income elasticity of export supply was further expected, since we assume that the development of lignocellulose-based industries requires substantial capital and expertise resources.

From the former observations, we infer that the development of future international demand is propelled by the proper establishment and management of lignocellulose-based industries. Compared to studies which analyses traditional wood product markets elasticities, the import demand for lignocellulsosic products tend to be more elastic. The price elastic nature of our elasticity coefficients might be an indication that the lignocellulosic products have at least one close substitute, which means that there are alternative options for customers to achieve the same benefit. An increase in product prices then will lead to a fall in demand due to customer changes to more attractive priced substitutes. To conclude, we suggest that a reduction of manufacturing costs (due to, e.g. scale effects or investments for technological developments), as well as increasing buying incentives, could be valuable instruments to lift these products out of their current niche. This, in turn, would improve the attractiveness of these end products and reduce their substitutability.

Based on our analysis we hypothesized that elasticity estimates of import demand and apparent consumption models are statistically interchangeable: To prove this assumption, we test the statistical equality of the two regression coefficients. Since the difference between the regression coefficients of import demand and apparent consumption elasticities of dissolving pulp are not statistically significant, we conclude that elasticity estimates of import demand and consumption can be used synonymously as, e.g., demand elasticities for adaption of economic equilibrium models for the forest products market such as the GFPM (Buongiorno et al. 2003) and the EFI-GTM

(Kallio et al. 2004). This allows for the inclusion of lignocellulosic products into global forest sector scenario modelling and thus, enhances policy analysis in light of an emerging forest based bioeconomy.

In a final remark, we want to note that, compared to the trade flows volumes of chemical derivatives, international trade flows of textile fibres appear to be smaller while fewer countries participate in trade. Since we know that both global textile fibres production and consumption is far higher than its traded volume and exceeds the production and consumption of chemical derivatives, we presume that fabricated textile fibres are mainly used domestically by the textile and apparel industries instead of being traded. To complement the results of the present work, the estimation of domestic production and consumption elasticities would, therefore, be an important next task. However, the major hindrance to overcome would be the identification of and access to suitable national production data for a reasonable amount of countries. We leave this undertaking to future work. Further research agenda could be extended to additional variables in supply and demand equations of lignocellulosic models, e.g. widen the statistical analysis towards the inclusion of cross-price elasticities of substitute products for having a better picture of the competitive market environment. Again, the availability of adequate data is a major hindrance for such analysis on global level.

Despite the challenges faced, we conclude that thorough data work and results testing - as presented in this work - allow for important insights into the development and functioning of emerging wood product markets sectors.

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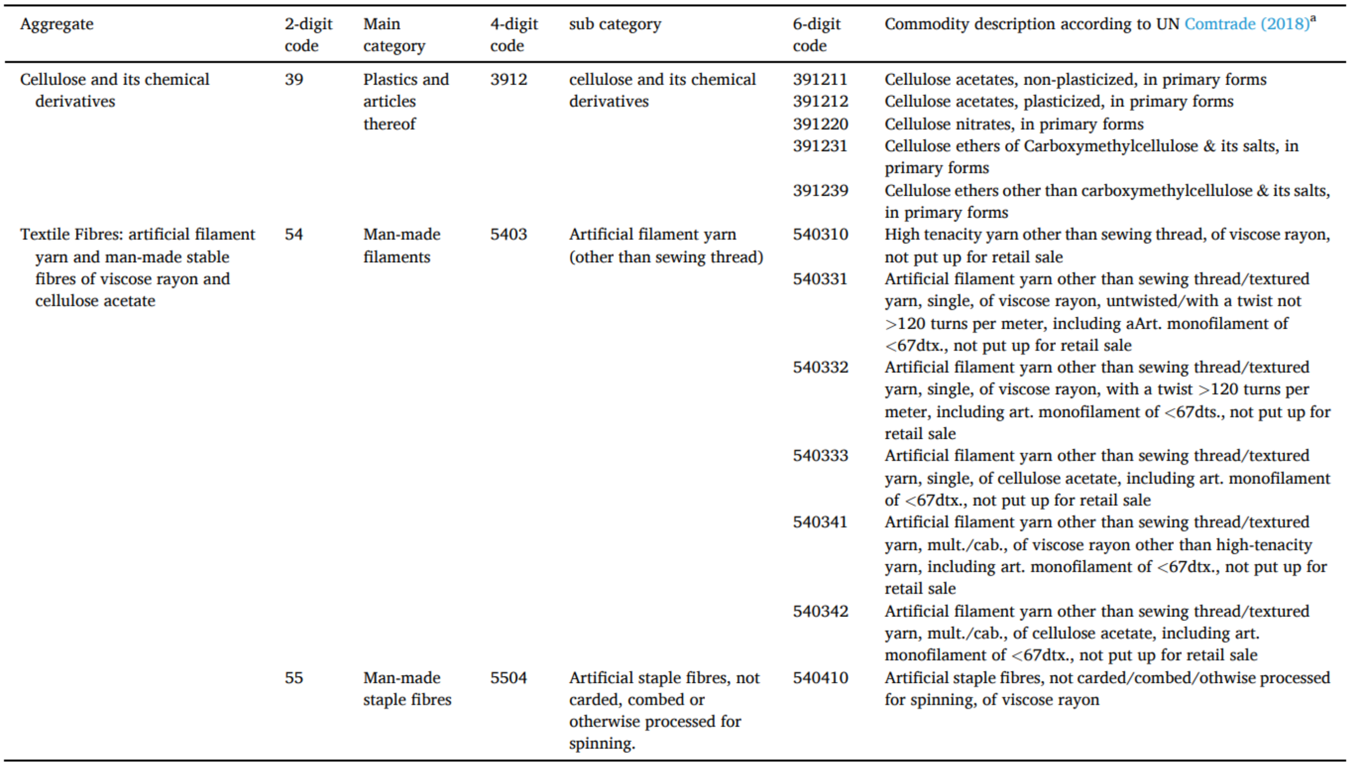
3.7. Annex

3.7.1. Input Data Clearing

To prevent biased modelling results due to messy incoming data, we clean and reduce information from the data bases. In reference to dissolving pulp, implausible data sets stating negative national consumption (export > import + production) in a given country and year are deleted from the input database. Further, raw data sets with single missing or imputed production, import or export entries are excluded from input data to ensure that model estimation only includes data reported by their respective countries. Trade data obtained from the UN Comtrade database distinguish between Imports and Re-Imports and Exports and Re-Exports, respectively. Re-Import and Re-Export data are excluded from model estimations since they play a minor role in terms of trading quantities but distort price calculations due to their higher trade values. In addition, we detect and remove outliers, which appear isolated in price data while reading out and importing input data into the data processing software; we clear outliers in price data based on a box-whisker approach. For this purpose, we set upper and lower whiskers twice the interquartile range above and below the first and third quartile of price data and exclude values above and below the upper and lower bounds from analysis. All data points smaller than one are excluded from further analysis in order to prevent problems while data are transformed logarithmically for model estimations.

3.8. Tables and Figures

Table 3.4 Decoding of commodity aggregates cellulose chemical derivatives and textile fibres for the present study



Aggregate	2-digit code	Main category	4-digit code	sub category	6-digit code	Commodity description according to UN Comtrade (2018)[a]
Cellulose and its chemical derivatives	39	Plastics and articles thereof	3912	cellulose and its chemical derivatives	391211	Cellulose acetates, non-plasticized, in primary forms
					391212	Cellulose acetates, plasticized, in primary forms
					391220	Cellulose nitrates, in primary forms
					391231	Cellulose ethers of Carboxymethylcellulose & its salts, in primary forms
					391239	Cellulose ethers other than carboxymethylcellulose & its salts, in primary forms
Textile Fibres: artificial filament yarn and man-made stable fibres of viscose rayon and cellulose acetate	54	Man-made filaments	5403	Artificial filament yarn (other than sewing thread)	540310	High tenacity yarn other than sewing thread, of viscose rayon, not put up for retail sale
					540331	Artificial filament yarn other than sewing thread/textured yarn, single, of viscose rayon, untwisted/with a twist not >120 turns per meter, including aArt. monofilament of <67dtx., not put up for retail sale
					540332	Artificial filament yarn other than sewing thread/textured yarn, single, of viscose rayon, with a twist >120 turns per meter, including art. monofilament of <67dts., not put up for retail sale
					540333	Artificial filament yarn other than sewing thread/textured yarn, single, of cellulose acetate, including art. monofilament of <67dtx., not put up for retail sale
					540341	Artificial filament yarn other than sewing thread/textured yarn, mult./cab., of viscose rayon other than high-tenacity yarn, including art. monofilament of <67dtx., not put up for retail sale
					540342	Artificial filament yarn other than sewing thread/textured yarn, mult./cab., of cellulose acetate, including art. monofilament of <67dtx., not put up for retail sale
	55	Man-made staple fibres	5504	Artificial staple fibres, not carded, combed or otherwise processed for spinning.	540410	Artificial staple fibres, not carded/combed/othwise processed for spinning, of viscose rayon

Note: [a]https://comtrade.un.org/db/mr/rfCommoditiesList.aspx?px=H2&cc=TOTAL

Table 3.5 Results showing the significant influence of sub periods in an aggregated model estimation with gdp, price, and dummy variable for the periods

		Dissolving Pulp			Chemical Derivatives			Textile Fibres		
		estimate	std.	Pr(>|t|)	estimate	std.	Pr(>|t|)	estimate	std.	Pr(>|t|)
apparent consumption	price	−1.075	0.392	**						
	income	1.367	0.044	***						
	period 2	1.329	0.016	***						
	period 3	−0.430	0.071	***						
	adj. R^2	0.418								
export supply	price	−2.312	0.585	***	−1.049	0.067	***	−1.425	0.109	***
	income	1.030	0.097	***	1.573	0.022	***	1.085	0.042	***
	period 2	1.663	0.089	***	−0.917	0,.022	***	1.680	0.026	***
	period 3	2.077	0.141	***	0.739	0.037	***	3.332	0.113	***
	adj. R^2	0.136			0.631			0.302		
import demand	price	−0.998	0.339	**	−1.256	0.086	***	−0.913	0.056	***
	income	1.233	0.051	***	1.253	0.017	***	1.431	0.020	***
	period 2	1.531	0.010	***	−1.520	0.094	***	1.486	0.065	***
	period 3	2.762	0.107	***	−1.420	0.060	***	1.738	0.087	***
	adj. R^2	0.360			0.803			0.572		

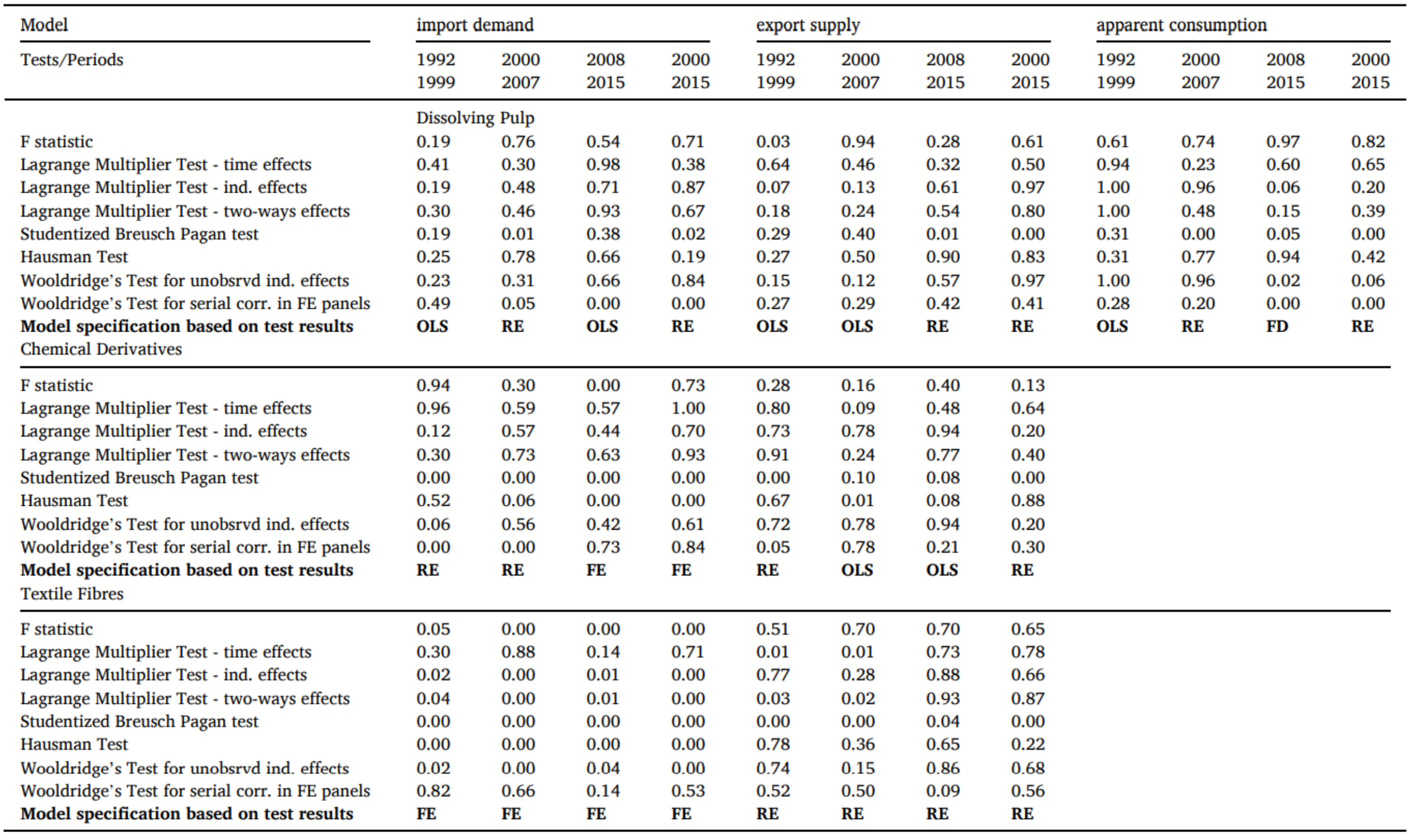
Note: Estimation method: FE within estimator with dummy variables for the different periods, formula logyit = β1 log Pit + β2 log GDPit + β2Dummy Period2 + β3Dummy Period3 + εit. Significance tests base on model specification tests and heteroscedasticity robust standard errors (HC3); std. is the standard error, the level of significance in difference of periods is *** < 0.000, ** 0.001, * 0.01

Table 3.6 Summary of main characteristics from 28 panel data sets employed for econometric model estimations

Period	T		n	N		n	N		n	N
1992–1999	8	DissPlp import demand	78	296	ChemDerv import demand	139	717	TexFibr import demand	126	633
2000–2007	8		63	216		170	1085		159	931
2008–2015	8		90	314		173	1111		160	908
2000–2015	16		96	530		180	2196		172	1869
1992–1999	8	DissPlp export supply	27	101	ChemDerv export supply	100	498	TexFibr export supply	82	391
2000–2007	8		27	105		124	764		101	540
2008–2015	8		38	149		160	938		100	515
2000–2015	16		39	254		137	1569		115	1055
1992–1999	8	DissPlp apparent consumption	78	265						
2000–2007	8		63	212						
2008–2015	8		89	317						
2000–2015	16		97	529						

Note: This the sub periods length (years), n the number of countries, and N the number of observations. DissPlp refers to dissolving pulp, ChemDerv to cellulose chemical derivatives, and TexFibr to lignocellulosic fibres.

Table 3.7 Results from econometric model specification and misspecification tests statistics



Model	import demand				export supply				apparent consumption			
Tests/Periods	1992 1999	2000 2007	2008 2015	2000 2015	1992 1999	2000 2007	2008 2015	2000 2015	1992 1999	2000 2007	2008 2015	2000 2015
	Dissolving Pulp											
F statistic	0.19	0.76	0.54	0.71	0.03	0.94	0.28	0.61	0.61	0.74	0.97	0.82
Lagrange Multiplier Test - time effects	0.41	0.30	0.98	0.38	0.64	0.46	0.32	0.50	0.94	0.23	0.60	0.65
Lagrange Multiplier Test - ind. effects	0.19	0.48	0.71	0.87	0.07	0.13	0.61	0.97	1.00	0.96	0.06	0.20
Lagrange Multiplier Test - two-ways effects	0.30	0.46	0.93	0.67	0.18	0.24	0.54	0.80	1.00	0.48	0.15	0.39
Studentized Breusch Pagan test	0.19	0.01	0.38	0.02	0.29	0.40	0.01	0.00	0.31	0.00	0.05	0.00
Hausman Test	0.25	0.78	0.66	0.19	0.27	0.50	0.90	0.83	0.31	0.77	0.94	0.42
Wooldridge's Test for unobsrvd ind. effects	0.23	0.31	0.66	0.84	0.15	0.12	0.57	0.97	1.00	0.96	0.02	0.06
Wooldridge's Test for serial corr. in FE panels	0.49	0.05	0.00	0.00	0.27	0.29	0.42	0.41	0.28	0.20	0.00	0.00
Model specification based on test results	**OLS**	**RE**	**OLS**	**RE**	**OLS**	**OLS**	**RE**	**RE**	**OLS**	**RE**	**FD**	**RE**
Chemical Derivatives												
F statistic	0.94	0.30	0.00	0.73	0.28	0.16	0.40	0.13				
Lagrange Multiplier Test - time effects	0.96	0.59	0.57	1.00	0.80	0.09	0.48	0.64				
Lagrange Multiplier Test - ind. effects	0.12	0.57	0.44	0.70	0.73	0.78	0.94	0.20				
Lagrange Multiplier Test - two-ways effects	0.30	0.73	0.63	0.93	0.91	0.24	0.77	0.40				
Studentized Breusch Pagan test	0.00	0.00	0.00	0.00	0.00	0.10	0.08	0.00				
Hausman Test	0.52	0.06	0.00	0.00	0.67	0.01	0.08	0.88				
Wooldridge's Test for unobsrvd ind. effects	0.06	0.56	0.42	0.61	0.72	0.78	0.94	0.20				
Wooldridge's Test for serial corr. in FE panels	0.00	0.00	0.73	0.84	0.05	0.78	0.21	0.30				
Model specification based on test results	**RE**	**RE**	**FE**	**FE**	**RE**	**OLS**	**OLS**	**RE**				
Textile Fibres												
F statistic	0.05	0.00	0.00	0.00	0.51	0.70	0.70	0.65				
Lagrange Multiplier Test - time effects	0.30	0.88	0.14	0.71	0.01	0.01	0.73	0.78				
Lagrange Multiplier Test - ind. effects	0.02	0.00	0.01	0.00	0.77	0.28	0.88	0.66				
Lagrange Multiplier Test - two-ways effects	0.04	0.00	0.01	0.00	0.03	0.02	0.93	0.87				
Studentized Breusch Pagan test	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00				
Hausman Test	0.00	0.00	0.00	0.00	0.78	0.36	0.65	0.22				
Wooldridge's Test for unobsrvd ind. effects	0.02	0.00	0.04	0.00	0.74	0.15	0.86	0.68				
Wooldridge's Test for serial corr. in FE panels	0.82	0.66	0.14	0.53	0.52	0.50	0.09	0.56				
Model specification based on test results	**FE**	**FE**	**FE**	**FE**	**RE**	**RE**	**RE**	**RE**				

Note: Regression models tested for their suitability are ordinary least square (OLS), fixed effects (FE), first-difference (FD), and random effects (RE) regression models. Test appreciations include the Lagrange Multiplier Test for time, individual and two-way effects (Breusch Pagan) for unbalanced panels, Woolridge's Test for unobserved individual effects, and Woolridge Test for serial correlation in FE panels.

Table 3.8 Dissolving pulp income and price elasticity estimations

		Dissolving Pulp														
time period		2000-2015														
		apparent consumption dissl plp					import demand dissl plp					export supply dissl plp				
years/countries/observations		T = 1-16	n = 97		N = 529		T = 1-16	n = 96		N = 530		T = 1-16	n = 39		N = 254	
model results		pooling model (OLS)														
residuals		min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
		-6.9377	-1.7259	0.0959	1.6189	5.4955	-8.0456	-1.6512	0.0456	2.0700	5.2012	-9.1079	-2.1123	0.7289	2.0498	5.6777
coefficients		estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
	intercept	-19.3372	2.2235	-8.6966	2.2E-16	***	-16.9914	2.2817	-7.4469	3.927E-13	***	-8.4178	0.5903	-1.4260	0.155113	
	price	-1.5947	0.3124	-5.1051	4.628E-07	***	-1.5321	0.2938	-5.2156	2.637E-07	***	-1.9312	0.6413	-3.0116	0.002864	**
	gdp	1.4409	0.0567	25.4170	2.2E-16	***	1.3282	0.0617	21.5346	2.2E-16	***	1.1136	0.1133	9.8308	2.2E-16	***
Adj. R-squared / F-statistic		0.4954	/ 260.14 on 2 and 526 DF, p-value: < 2.22e-16				0.4409	/ 209.594 on 2 and 527 DF, p-value: < 2.22e-16				0.2223	/ 37.1558 on 2 and 251 DF, p-value: 7.336e-15			
model results		oneway individual effects within model														
residuals		min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
		-7.2555	-1.5082	0.0000	1.4340	6.0046	-7.0175	-1.4672		1.5170	5.6944	-9.8585	-1.9293	0.2795	1.9348	5.9812
coefficients		estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
	price	-1.3661	0.4398	-3.1063	2.02E-03	**	-1.2411	0.3896	-3.1855	0.0016	**	-2.0776	0.7159	-2.9021	0.0041	**
	gdp	1.4121	0.0620	22.7842	2.2E-16	***	1.2809	0.0706	18.1317	2.2E-16	***	1.1399	0.1294	8.8083	4.491E-16	***
Adj. R-squared / F-statistic		0.3457	/ 188.51 on 2 and 430 DF, p-value: < 2.22e-16				0.2753	/ 148.992 on 2 and 432 DF, p-value: < 2.22e-16				0.0916	/ 32.7569 on 2 and 213 DF, p-value: 3.9469e-13			
model results		oneway individual effect random effects model														
effects		var	sted.dev		share		var	sted.dev		share		var	sted.dev		share	
	idiosyncratic	6.4140	2.5330		1.0000		6.5600	2.5610		1.0000		9.0660	3.0110		1.0000	
	individual			0					0					0		
	theta			0					0					0		
residuals		min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
		-6.9377	-1.7259	0.0959	1.6189	5.4955	-8.0456	-1.6512	0.0456	2.0700	5.2012	-9.1079	-2.1123	0.7289	2.0498	5.6777
coefficients		estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
	intercept	-19.3372	2.2235	-8.6966	2.2E-16	***	-16.9914	2.2817	-7.4469	3.927E-13	***	-8.4178	0.5903	-1.4260	0.155113	
	price	-1.5947	0.3124	-5.1051	4.628E-07	***	-1.5321	0.2938	-5.2156	2.637E-07	***	-1.9312	0.6413	-3.0116	0.002864	**
	gdp	1.4409	0.0567	25.4170	2.2E-16	***	1.3282	0.0617	21.5346	2.2E-16	***	1.1136	0.1133	9.8308	2.2E-16	***
Adj. R-squared / F-statistic		0.4954	/ 260.14 on 2 and 526 DF, p-value: < 2.22e-16				0.4409	/ 209.594 on 2 and 527 DF, p-value: < 2.22e-16				0.2223	/ 37.1558 on 2 and 251 DF, p-value: 7.336e-15			
model results		oneway individual effects first-difference model														
residuals		min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max		1st qu	median	3d qu	max
		-10.3344	-2.6402	-0.0256	2.3922	9.1538	-9.3055	-2.6106	-0.0974	2.4747	9.4702	-11.5987	-2.4892	0.0276	2.9903	10.3702
coefficients		estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
	price	-1.5300	0.3500	-4.3722	1.55E-05	***	-1.5871	0.2999	-5.2916	1.94E-07	***	-1.8071	0.5432	-3.3271	1.03E-03	**
	gdp	1.4697	0.5610	26.1967	2.2E-16	***	1.3271	0.0651	20.3851	2.2E-16	***	1.2395	0.1135	10.9182	2.2E-16	***
Adj. R-squared / F-statistic		0.4719	/ 386.118 on 1 and 430 DF, p-value: < 2.22e-16				0.4268	/ 162.169 on 2 and 431 DF, p-value: < 2.22e-16				0.2611	/ 38.8029 on 2 and 212 DF, p-value: 3.9984e-16			

Table 3.8 (continued)

time period	2008-2015														
	apparent consumption dissl plp					import demand dissl plp					export supply dissl plp				
years/countries/observations	T = 1-8	n = 89		N = 317		T = 1-8	n = 90		N = 314		T = 1-8	n = 38		N = 149	
model results	pooling model (OLS)														
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-6.5061	-1.9549	0.1008	1.6871	5.8256	-7.7945	-1.7689	0.0931	2.1424	4.8987	-9.1032	-2.5008	0.5816	2.4556	5.7091
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	-18.6546	2.5570	-7.2955	2.446E-12	***	-18.1245	2.4263	-5.8977	9.61E-09	***	-6.8346	6.3189	-1.0816	0.2812	
price	-1.8971	0.3433	-5.5267	6.864E-08	***	-1.6725	0.3453	-4.8443	2.008E-06	***	-2.4663	0.6508	-3.7900	0.0002	***
gdp	1.4846	0.0754	19.6821	2.2E-16	***	1.3972	0.0865	16.1544	2.2E-16	***	1.1933	0.1545	7.7226	1.667E-12	***
Adj. R-squared / F-statistic	0.5029	/ 160.866 on 2 and 314 DF, p-value: < 2.22e-16				0.4584	/ 133.479 on 2 and 311 DF, p-value: < 2.22e-16				0.2150	21.2713 on 2 and 146 DF, p-value: 7.8141e-09			
model results	oneway individual effects within model														
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-6.8550	-1.5567	0.0000	1.5777	5.5719	-6.6769	-1.5279	0.0000	1.7209	6.1671	-7.4849	-1.7051	0.0090	1.8902	6.3868
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	-1.8429	0.4229	-4.3580	1.99E-05	***	-1.4804	0.3396	-4.3592	2.00E-05	***	-2.5894	0.6850	-3.7803	0.0003	***
gdp	1.4674	0.0899	16.3220	2.2E-16	***	1.3935	0.0824	16.9155	2.2E-16	***	1.2425	0.1846	6.7300	8.209E-10	***
Adj. R-squared / F-statistic	0.2762	/ 105.29 on 2 and 226 DF, p-value: < 2.22e-16				0.2465	/ 96.7027 on 2 and 222 DF, p-value: < 2.22e-16				-0.0361	/ 16.9185 on 2 and 109 DF, p-value: 3.9896e-07			
model results	oneway individual effect random effects model														
effects	var	sted.dev		share		var	sted.dev		share		var	sted.dev		share	
idiosyncratic	7.4800	2.7350		1.0000		7.0690	2.6590		1.0000		10.2837	3.2068		0.9470	
individual			0					0			0.5807	7620.0000		0.0530	
theta			0					0			0.0271	0.0968	0.1358	0.1701	0.1701
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-6.5061	-1.9549	0.1008	1.6871	5.8256	-7.7945	-1.7689	0.0931	2.1424	4.8987	-8.7933	2.3183	0.6675	2.2824	5.3708
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	-18.6546	2.5570	-7.2955	2.446E-12	***	-18.1245	1.8504	-9.7950	2.2E-16	***	-6.3499	6.5000	-0.9769	0.3302	
price	-1.8971	0.3433	-5.5267	6.864E-08	***	-1.6725	0.2781	-6.0142	5.069E-09	***	-2.5199	0.6384	-3.9470	0.0001	***
gdp	1.4846	0.0754	19.6821	2.2E-16	***	1.3972	0.0453	30.8514	2.2E-16	***	1.1894	0.1558	7.6320	2.758E-12	***
Adj. R-squared / F-statistic	0.5029	/ 160.866 on 2 and 314 DF, p-value: < 2.22e-16				0.4584	/ 133.479 on 2 and 311 DF, p-value: < 2.22e-16				0.2473	/ 25.3062 on 2 and 146 DF, p-value: 3.6658e-10			
model results	oneway individual effects first-difference model														
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-10.1163	-2.6164	-0.0897	2.8310	8.9026	-8.0935	-3.1085	-0.1521	2.7790	9.7979	-11.2281	-2.5816	0.4593	3.1235	10.1151
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	-1.8059	0.4723	-3.8234	1.70E-04	***	-1.6067	0.3158	-5.0872	7.75E-07	***	-2.3451	0.7611	-3.0811	0.0026	**
gdp	1.5173	0.0786	19.3091	2.2E-16	***	1.3999	0.0774	18.0882	2.2E-16	***	1.4868	0.2342	6.3491	5.23E-09	***
Adj. R-squared / F-statistic	0.4492	/ 93.5616 on 2 and 225 DF, p-value: < 2.22e-16				0.4219	/ 82.3617 on 2 and 221 DF, p-value: < 2.22e-16				0.2573	/ 20.0493 on 2 and 108 DF, p-value: 4.8197e-09			

Table 3.8 (continued)

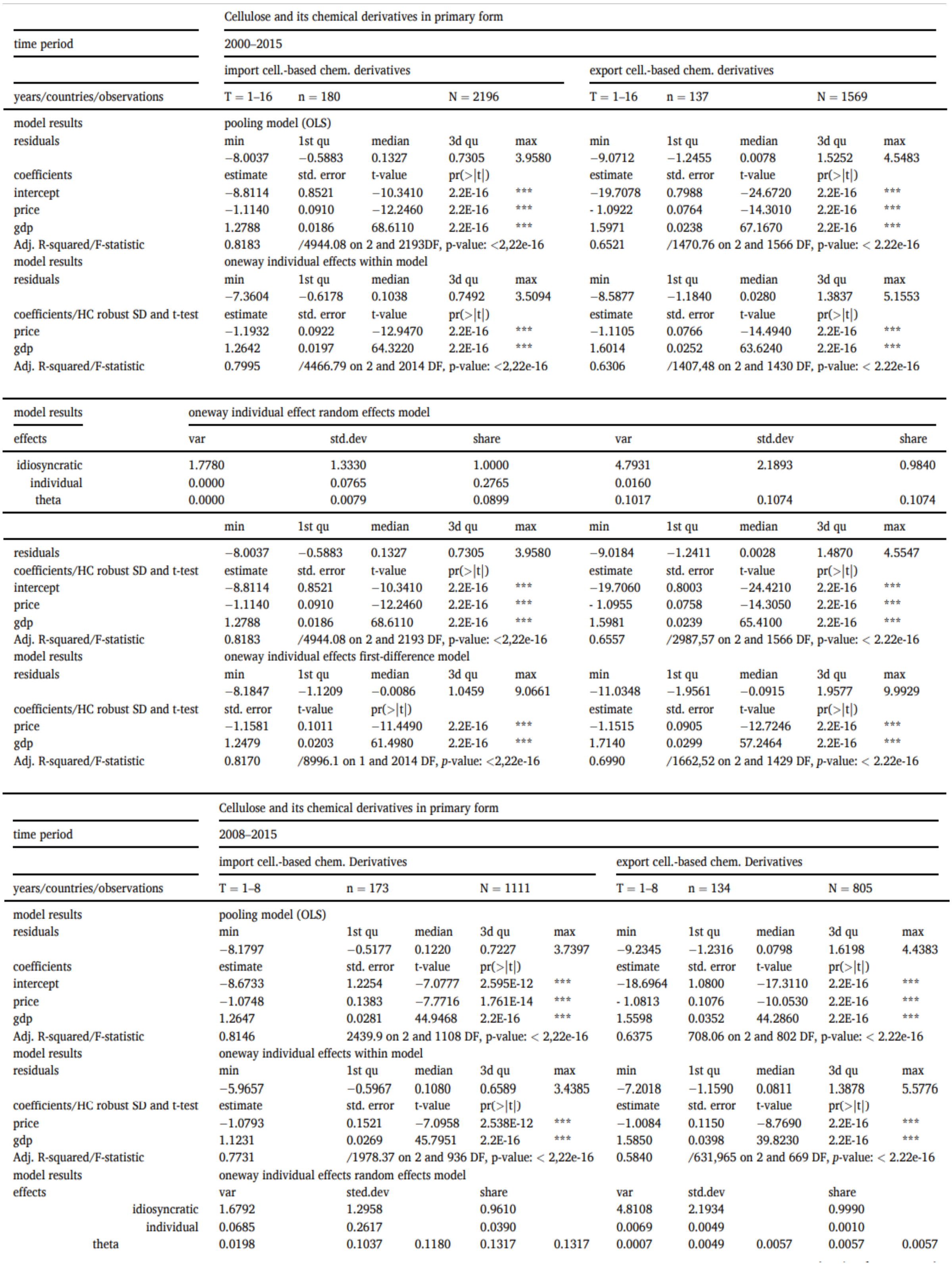
time period								2000-2007							
			apparent consumption dissl plp					import demand dissl plp						export supply dissl plp	
years/countries/observations	T = 1-8	n = 63		N =212		T = 1-8	n = 63		N = 216		T = 1-8	n = 27		N = 105	
model results								pooling model (OLS)							
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-6.9890	-1.2835	0.1126	1.2963	4.1013	-7.0152	-1.2231	0.0182	1.6966	3.9907	-9.2194	-1.2604	0.7457	1.5481	5.0189
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	-31.0643	3.4401	-9.0301	2.2E-16	***	-24.7233	3.5947	-6.8777	6.649E-11	***	-14.3260	9.1718	-1.5620	0.1214	
price	0.7623	0.4883	1.5973	0.1117		0.4674	0.5506	0.8490	0.3968		-0.8724	0.7477	-1.1668	0.2460	
gdp	1.3009	0.0903	14.4132	2.2E-16	***	1.1260	0.1038	10.8532	2.2E-16	***	1.0646	0.1882	5.6578	1.411E-07	***
Adj. R-squared / F-statistic	0.4950	/ 104.428 on 2 and 209 DF, p-value: < 2.22e-16				0.4058	/ 74.3997 on 2 and 213 DF, p-value: < 2.22e-16				0.2424	17.6392 on 2 and 102 DF, p-value: 2.6357e-07			
model results								oneway individual effects within model							
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-4.9435	-1.1259	0.0000	1.1509	5.6595	-6.1345	-1.1143	0.0000	1.1220	4.1144	-9.4483	-1.1515	0.2358	1.4896	4.3830
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	0.8041	0.7256	1.1081	0.2696		0.5711	0.8509	0.6712	0.5031		-1.3918	0.9099	-1.5296	0.1303	.
gdp	1.3419	0.0965	13.9042	2.2E-16	***	1.1602	0.1202	0.9652	2.2E-16	***	0.9621	0.1991	4.8319	6.869E-06	***
Adj. R-squared / F-statistic	0.3069	/ 78.7039 on 2 and 147 DF, p-value: < 2.22e-16				0.2000	/ 58.8748 on 2 and 151 DF, p-value: < 2.22e-16				-0.0546	/ 11.3088 on 2 and 76 DF, p-value: 5.0195e-05			
model results								oneway individual effect random effects model							
effects	var	sted.dev		share		var	sted.dev		share		var	sted.dev		share	
idiosyncratic	4.8660	2.2060		1.0000		5.2530	2.2920		1.0000		7.3120	2.7040		1.0000	
individual			0					0					0		
theta			0					0					0		
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-6.9890	-1.2835	0.1126	1.2963	4.1013	-7.0152	-1.2231	0.0182	1.6966	3.9907	-9.2194	-1.2604	0.7457	1.5481	5.0189
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	-31.0643	3.4401	-9.0301	2.2E-16	***	-24.7233	3.5947	-6.8777	6.649E-11	***	-14.3260	9.1718	-1.5620	0.1214	
price	0.7623	0.4883	1.5973	0.1117		0.4674	0.5506	0.8490	0.3968		-0.8724	0.7477	-1.1668	0.2460	
gdp	1.3009	0.0903	14.4132	2.2E-16	***	1.1260	0.1038	10.8532	2.2E-16	***	1.0646	0.1882	5.6578	1.411E-07	***
Adj. R-squared / F-statistic	0.4950	/ 104.428 on 2 and 209 DF, p-value: < 2.22e-16				0.4058	/ 74.3997 on 2 and 213 DF, p-value: < 2.22e-16				0.2424	/ 17.6392 on 2 and 102 DF, p-value: 2.6357e-07			
model results								oneway individual effects first-difference model							
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-7.1631	-2.1016	-0.0798	1.5588	7.4072	-7.4355	-2.2067	-0.2540	2.0428	8.6533	-11.5513	-1.9397	0.3119	2.3884	9.8965
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	1.1044	0.5589	1.9760	0.0500	.	0.6430	0.7517	0.8554	0.3937		-1.3378	0.8208	-1.6300	0.1073	
gdp	1.3879	0.0876	15.8359	2.2E-16	***	1.2607	0.1149	10.9688	2.2E-16	***	1.1236	0.1418	7.9267	1.645E-11	***
Adj. R-squared / F-statistic	0.5380	/ 87.1769 on 2 and 146 DF, p-value: < 2.22e-16				0.4694	/ 68.2438 on 1 and 150 DF, p-value: < 2.22e-16				0.2837	/ 16.246 on 2 and 75 DF, p-value: 1.3746-06			

Table 3.8 (continued)

time period								1992-1999							
			apparent consumption dissl plp					import demand dissl plp					export supply dissl plp		
years/countries/observations	T = 1-8	n = 78		N =265		T = 1-8	n = 78		N = 269		T = 1-8	n = 27		N = 101	
model results								pooling model (OLS)							
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-6.9673	-1.1182	0.0781	1.4572	4.6250	-6.4431	-1.1051	0.0598	1.2434	4.1232	-7.5667	-1.7217	0.0851	2.1986	5.2800
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	-25.5717	3.2579	-7.8492	1.073E-13	***	-22.7742	2.9066	-7.8354	1.124E-13	***	-5.7154	7.9231	-0.7214	0.4724	
price	-0.1837	0.5373	-0.3418	0.7328		0.0420	0.4876	0.0861	0.9314		-1.3478	1.0219	-1.3189	0.1903	
gdp	1.3491	0.0594	22.7096	2.2E-16	***	1.1660	0.0660	17.6757	2.2E-16	***	0.8523	0.1764	4.8315	5.01E-06	***
Adj. R-squared / F-statistic	0.5609	/ 169.635 on 2 and 262 DF, p-value: < 2.22e-16				0.5330	/ 168.736 on 2 and 266 DF, p-value: < 2.22e-16				0.1931	/ 21.8243 on 2 and 98 DF, p-value: 1.4477e-08			
model results								oneway individual effects within model							
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-5.5388	-1.0702	0.0000	1.2100	5.2909	-5.6757	-0.9282	0.0000	0.8622	4.9395	-4.9508	-1.3337	0.0000	1.3296	5.3634
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	0.2668	0.6668	0.4001	0.6895		0.3438	0.6123	0.5614	0.5752		-2.6470	0.9251	-2.8614	0.0055	**
gdp	1.3642	0.0662	20.5933	2.2E-16	***	1.1959	0.0705	16.9597	2.2E-16	***	0.9621	0.2276	4.0749	0.0001	***
Adj. R-squared / F-statistic	0.4151	/ 133.184 on 2 and 185 DF, p-value: < 2.22e-16				0.4118	/ 133.299 on 2 and 189 DF, p-value: < 2.22e-16				-0.0186	/ 13.0872 on 2 and 72 DF, p-value: 1.4192e-05			
model results								oneway individual effect random effects model							
effects	var	sted.dev		share		var	sted.dev		share		var	sted.dev		share	
idiosyncratic	4.4530	2.1100		1.0000		3.4892	1.8679		0.9540		5.7490	2.3980		0.8150	
individual			0			0.1686	0.4106		0.0460		1.3080	1.1440		0.1850	
theta			0			0.0233	0.0654	0.1025	0.1355	0.1507	0.0974	0.2765	0.3790	0.3790	0.4046
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-6.9673	-1.1182	0.0781	1.4572	4.6250	-6.3294	-1.1293	0.024	1.1809	4.0722	-6.4977	-1.8545	-0.0317	1.9681	4.5825
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	-25.5717	3.2579	-7.8492	1.073E-13	***	-22.9186	2.9182	-7.8537	9.982E-14	***	-3.9581	7.8934	5014	0.6172	
price	-0.1837	0.5373	-0.3418	0.7328		0.0639	0.4949	0.1291	0.8974		-1.6342	0.9774	-1.6719	0.0977	.
gdp	1.3491	0.0594	22.7096	2.2E-16	***	1.1663	0.0647	18.0171	2.2E-16	***	0.8593	0.1807	4.7543	6.841E-06	***
Adj. R-squared / F-statistic	0.5609	/ 169.635 on 2 and 262 DF, p-value: < 2.22e-16				0.5560	/ 168.736 on 2 and 266 DF, p-value: < 2.22e-16				0.2941	/ 21.8243 on 2 and 98 DF, p-value: 1.4477e-08			
model results								oneway individual effects first-difference model							
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	-8.9489	-2.0849	-0.1646	2.1912	8.4332	-5.5499	-1.6796	-0.0064	2.0029	6.5818	-6.1870	-2.1539	-0.1645	2.3597	6.1085
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	0.1181	0.5563	0.2124	0.8457		0.3472	0.4444	0.7814	0.4356		-1.9859	0.8939	-2.2217	0.02949	*
gdp	1.4249	0.0601	23.6979	2.2E-16	***	1.2294	0.0560	21.9722	2.2E-16	***	1.1472	0.2299	4.9904	4.134E-06	***
Adj. R-squared / F-statistic	0.6117	/ 147.494 on 2 and 184 DF, p-value: < 2.22e-16				0.6006	/ 143.88 on 2 and 188 DF, p-value: < 2.22e-16				0.3391	/ 19.7232 on 2 and 71 DF, p-value: 1.5409e-07			

Note: results for export supply and import demand models obtained with four model types (pooling, fixed effects, first-difference, and random effects estimator) including standard errors, t-values, probabilities and significance levels as well as F-statistics and adjusted R-Square to indicate the explanatory power of the respective model. Model variables are con~dwuv+gdp, T refers to the years, n to the number of countries, and N to the number of observations

Table 3.9 Cellulose-based chemical derivatives income and price elasticity estimations



	Cellulose and its chemical derivatives in primary form									
time period	2000–2015									
	import cell.-based chem. derivatives					export cell.-based chem. derivatives				
years/countries/observations	T = 1–16	n = 180		N = 2196		T = 1–16	n = 137		N = 1569	
model results	pooling model (OLS)									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−8.0037	−0.5883	0.1327	0.7305	3.9580	−9.0712	−1.2455	0.0078	1.5252	4.5483
coefficients	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
intercept	−8.8114	0.8521	−10.3410	2.2E-16	***	−19.7078	0.7988	−24.6720	2.2E-16	***
price	−1.1140	0.0910	−12.2460	2.2E-16	***	- 1.0922	0.0764	−14.3010	2.2E-16	***
gdp	1.2788	0.0186	68.6110	2.2E-16	***	1.5971	0.0238	67.1670	2.2E-16	***
Adj. R-squared/F-statistic	0.8183	/4944.08 on 2 and 2193DF, p-value: <2,22e-16				0.6521	/1470.76 on 2 and 1566 DF, p-value: < 2.22e-16			
model results	oneway individual effects within model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−7.3604	−0.6178	0.1038	0.7492	3.5094	−8.5877	−1.1840	0.0280	1.3837	5.1553
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
price	−1.1932	0.0922	−12.9470	2.2E-16	***	−1.1105	0.0766	−14.4940	2.2E-16	***
gdp	1.2642	0.0197	64.3220	2.2E-16	***	1.6014	0.0252	63.6240	2.2E-16	***
Adj. R-squared/F-statistic	0.7995	/4466.79 on 2 and 2014 DF, p-value: <2,22e-16				0.6306	/1407,48 on 2 and 1430 DF, p-value: < 2.22e-16			
model results	oneway individual effect random effects model									
effects	var	std.dev		share		var		std.dev		share
idiosyncratic	1.7780	1.3330		1.0000		4.7931		2.1893		0.9840
individual	0.0000	0.0765		0.2765		0.0160				
theta	0.0000	0.0079		0.0899		0.1017		0.1074		0.1074
	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
residuals	−8.0037	−0.5883	0.1327	0.7305	3.9580	−9.0184	−1.2411	0.0028	1.4870	4.5547
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
intercept	−8.8114	0.8521	−10.3410	2.2E-16	***	−19.7060	0.8003	−24.4210	2.2E-16	***
price	−1.1140	0.0910	−12.2460	2.2E-16	***	- 1.0955	0.0758	−14.3050	2.2E-16	***
gdp	1.2788	0.0186	68.6110	2.2E-16	***	1.5981	0.0239	65.4100	2.2E-16	***
Adj. R-squared/F-statistic	0.8183	/4944.08 on 2 and 2193 DF, p-value: <2,22e-16				0.6557	/2987,57 on 2 and 1566 DF, p-value: < 2.22e-16			
model results	oneway individual effects first-difference model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−8.1847	−1.1209	−0.0086	1.0459	9.0661	−11.0348	−1.9561	−0.0915	1.9577	9.9929
coefficients/HC robust SD and t-test	std. error	t-value	pr(>|t|)			estimate	std. error	t-value	pr(>|t|)	
price	−1.1581	0.1011	−11.4490	2.2E-16	***	−1.1515	0.0905	−12.7246	2.2E-16	***
gdp	1.2479	0.0203	61.4980	2.2E-16	***	1.7140	0.0299	57.2464	2.2E-16	***
Adj. R-squared/F-statistic	0.8170	/8996.1 on 1 and 2014 DF, *p*-value: <2,22e-16				0.6990	/1662,52 on 2 and 1429 DF, *p*-value: < 2.22e-16			

	Cellulose and its chemical derivatives in primary form									
time period	2008–2015									
	import cell.-based chem. Derivatives					export cell.-based chem. Derivatives				
years/countries/observations	T = 1–8	n = 173		N = 1111		T = 1–8	n = 134		N = 805	
model results	pooling model (OLS)									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−8.1797	−0.5177	0.1220	0.7227	3.7397	−9.2345	−1.2316	0.0798	1.6198	4.4383
coefficients	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
intercept	−8.6733	1.2254	−7.0777	2.595E-12	***	−18.6964	1.0800	−17.3110	2.2E-16	***
price	−1.0748	0.1383	−7.7716	1.761E-14	***	- 1.0813	0.1076	−10.0530	2.2E-16	***
gdp	1.2647	0.0281	44.9468	2.2E-16	***	1.5598	0.0352	44.2860	2.2E-16	***
Adj. R-squared/F-statistic	0.8146	2439.9 on 2 and 1108 DF, p-value: < 2,22e-16				0.6375	708.06 on 2 and 802 DF, p-value: < 2.22e-16			
model results	oneway individual effects within model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−5.9657	−0.5967	0.1080	0.6589	3.4385	−7.2018	−1.1590	0.0811	1.3878	5.5776
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
price	−1.0793	0.1521	−7.0958	2.538E-12	***	−1.0084	0.1150	−8.7690	2.2E-16	***
gdp	1.1231	0.0269	45.7951	2.2E-16	***	1.5850	0.0398	39.8230	2.2E-16	***
Adj. R-squared/F-statistic	0.7731	/1978.37 on 2 and 936 DF, p-value: < 2,22e-16				0.5840	/631,965 on 2 and 669 DF, *p*-value: < 2.22e-16			
model results	oneway individual effects random effects model									
effects	var	sted.dev		share		var	std.dev		share	
idiosyncratic	1.6792	1.2958		0.9610		4.8108	2.1934		0.9990	
individual	0.0685	0.2617		0.0390		0.0069	0.0049		0.0010	
theta	0.0198	0.1037	0.1180	0.1317	0.1317	0.0007	0.0049	0.0057	0.0057	0.0057

Table 3.9 (continued)

	Cellulose and its chemical derivatives in primary form									
time period	2008–2015									
	import cell.-based chem. Derivatives					export cell.-based chem. Derivatives				
years/countries/observations	T = 1–8	n = 173		N = 1111		T = 1–8	n = 134		N = 805	
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−8.0032	−0.5192	0.1268	0.7090	3.6937	−9.2061	−1.1900	0.0795	1.6189	4.4161
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
intercept	−8.5654	1.2400	−6.9078	8.283E-12	***	−18.7061	1.0795	−17.3320	2.2E-16	***
price	−1.0759	0.1395	−7.7127	2.733E-14	***	1.0808	0.1075	−10.0490	2.2E-16	***
gdp	1.2606	0.0278	45.3684	2.2E-16	***	1.5600	0.0352	44.2680	2.2E-16	***
Adj. R-squared/F-statistic	0.8128	/2411.26 on 2 and 1108 DF, p-value: < 2,22e-16				0.6377	/708.555 on 2 and 802 DF, p-value: < 2.22e-16			
model results	oneway individual effects first-difference model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−7.0304	−1.0901	−0.0434	0.9763	7.8714	−11.2120	−1.9629	−0.1773	1.9022	8.9871
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
price	−1.1692	0.1704	−6.8592	2.2E-16	***	−1.1368	0.1496	−7.6011	9.972E-14	***
gdp	1.2257	0.0271	45.2884	2.2E-16	***	1.6423	0.0488	33.6301	2.2E-16	***
Adj. R-squared/F-statistic	0.8138	/4096,5 on 1 and 936 DF, p-value: < 2,22e-16				0.6857	/1461.64 on 1 and 669 DF, *p*-value: < 2.22e-16			

	Cellulose and its chemical derivatives in primary form									
time period	2000–2007									
	import cell.-based chem. derivatives					export cell.-based chem. derivatives				
years/countries/observations	T = 1–8	n = 170		N = 1085		T = 1–8	n = 124		N = 764	
model results	pooling model (OLS)									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−7.90016	−0.64993	0.16685	0.72357	4.14391	−8.88663	−1.2544	−0.04709	1.344598	4.697481
coefficients	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
intercept	−8.3910	1.1319	−7.4131	2.483E-13	***	−19.9719	1.1263	−17.7320	2.2E-16	***
price	−1.2055	0.1187	−10.1533	2.2E-16	***	−1.1731	0.1127	−10.4120	2.2E-16	***
gdp	1.2876	0.0243	53.0572	2.2E-16	***	1.6272	0.0339	48.0360	2.2E-16	***
Adj. R-squared/F-statistic	0.8235	/2531.86 on 2 and 1082 DF, p-value: < 2.22e-16				0.6679	/768.499 on 2 and 761 DF, p-value: < 2.22e-16			
model results	oneway individual effects within model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−7.1955	−0.5668	0.0410	0.6788	3.6908	−7.6282	−1.1752	0.0032	1.2498	5.1664
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
price	−1.2783	0.1244	−10.2770	2.2E-16	***	−1.1181	0.1185	−9.4394	2.2E-16	***
gdp	1.2753	0.0252	50.6890	2.2E-16	***	1.6736	0.0381	43.8881	2.2E-16	***
Adj. R-squared/F-statistic	0.7929	/2160,52 on 2 and 913 DF, p-value: < 2.22e-16				0.6270	/703,887 on 2 and 638 DF, p-value: < 2.22e-16			
model results	oneway individual effect random effects model									
effects	var	std.dev		share		var	std.dev		share	
idiosyncratic	1.7247	1.3133		0.9940		4.7502	2.1795		0.9870	
individual	0.0104	0.1018		0.0060		0.0616	0.2482		0.0130	
theta	0.0030	0.0204	0.0232	0.0232	0.0232	0.0064	0.0425	0.0482	0.0482	0.0482
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−7.8885	−0.6460	0.1620	0.7156	4.1279	−8.8322	−1.2474	−0.0575	1.3548	4.6789
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
intercept	−8.3562	1.1341	−7.3683	2.2E-16	***	−20.0756	1.1239	−17.8620	2.2E-16	***
price	−1.2083	0.1187	−10.1771	2.2E-16	***	−1.1687	0.1127	−10.3700	2.2E-16	***
gdp	1.2872	0.0243	53.0533	2.2E-16	***	1.6299	0.0339	48.0130	2.2E-16	***
Adj. R-squared/F-statistic	0.8236	/2531,86 on 2 and 1082 DF, p-value: < 2.22e-16				0.6699	/1550,14 on 2 and 761 DF, *p*-value: < 2.22e-16			
model results	oneway individual effects first-difference model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−7.9596	−1.2152	−0.0192	1.0742	6.9718	−10.7093	−1.9417	−0.0218	1.9425	9.5498
coefficients/HC robust SD and t-test	std. error	t-value	pr(>|t|)			estimate	std. error	t-value	pr(>|t|)	
price	−1.1612	0.1456	−7.9743	2.2E-16	***	−1.2262	0.1306	−9.3928	2.2E-16	***
gdp	1.2905	0.0316	40.7917	2.2E-16	***	1.7461	0.0404	43.1843	2.2E-16	***
Adj. R-squared/F-statistic	0.8131	/3977,56 on 1 and 913 DF, *p*-value: < 2.22e-16				0.7176	/812,768 on 2 and 637 DF, *p*-value: < 2.22e-16			

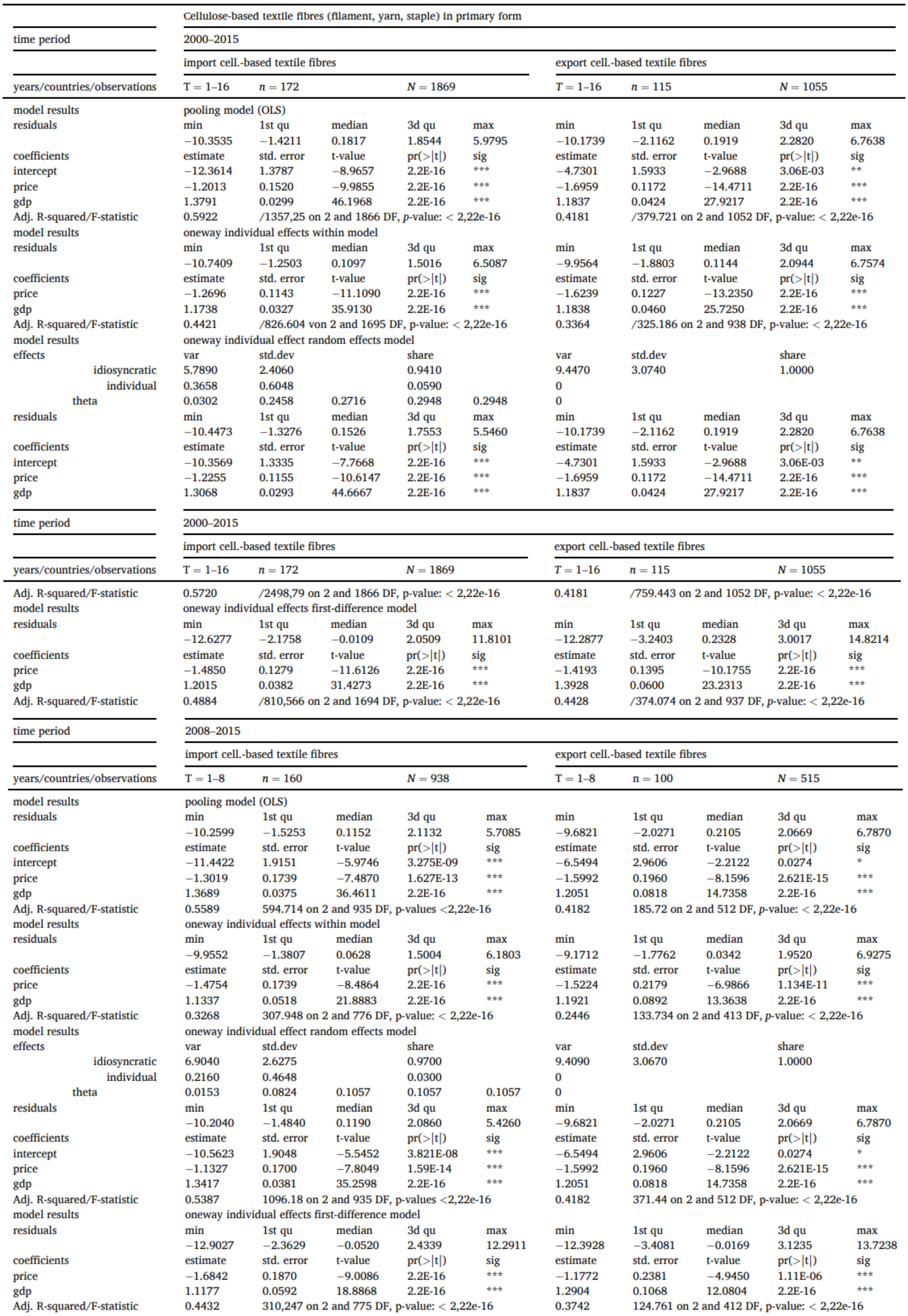
	Cellulose and its chemical derivatives in primary form									
time period	1992–1999									
	import cell.-based chem. derivatives					export cell.-based chem. derivatives				
years/countries/observations	T = 1–8	n = 139		N = 717		T = 1–8	n = 100		N = 498	
model results	pooling model (OLS)									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−9.18907	−0.49482	0.19914	0.073207	3.72093	−6.90586	−1.27787	−0.05971	1.178335	5.371348
coefficients	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
intercept	−5.0149	1.8199	−2.7556	0.0060	***	−19.4505	1.5490	−12.5569	2.2E-16	***
price	−1.4068	0.1790	−7.8574	0.0000	***	- 0.8791	0.1546	−5.6867	2.217E-08	***
gdp	1.2258	0.0294	41.7178	0.0000	***	1.5174	0.0381	39.7800	2.2E-16	***

Table 3.9 (continued)

	Cellulose and its chemical derivatives in primary form									
time period	1992–1999									
	import cell.-based chem. derivatives					export cell.-based chem. derivatives				
years/countries/observations	T = 1–8	n = 139		N = 717		T = 1–8	n = 100		N = 498	
Adj. R-squared/F-statistic	0.8104	/1531.18 on 2 and 714 DF, p-value: < 2.22e-16				0.6554	/473.65 on 2 and 495 DF, *p*-value: < 2.22e-16			
model results	oneway individual effects within model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−8.561979	−0.515749	0.076895	0.762725	3.247587	−5.714	−1.22136	−0.15095	1.15004	5.71282
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
price	−1.4272	0.1926	−7.4086	0.0000	***	−0.8178	0.1490	−5.4884	1.016E-07	***
gdp	1.2123	0.0312	38.8666	0.0000	***	1.4948	0.0436	34.2870	2.2E-16	***
Adj. R-squared/F-statistic	0.7566	/1182,8 on 2 and 576 DF, p-value: < 2.22e-16				0.5669	/375.777 on 2 and 396 DF, *p*-value: < 2.22e-16			
model results	oneway individual effect random effects model									
effects	var	std.dev		share		var	std.dev		share	
idiosyncratic	1.9320	1.3900		1.0000		4.2688	2.0661		0.9790	
individual	0.0000					0.0936	0.3060		0.0210	
theta	0.0000					0.0108	0.0507	0.0689	0.0777	0.0777
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−9.1807	−0.4948	0.1991	0.7321	3.7209	−6.7800	−1.2640	−0.0540	1.1990	5.3260
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
intercept	−5.0149	1.8199	−2.7556	0.0060	**	−19.4524	1.5315	−12.7017	2.2E-16	***
price	−1.4068	0.1790	−7.8574	1.445E-14	***	- 0.8718	0.1532	−5.6906	2.17E-08	***
gdp	1.2258	0.0294	41.7178	2.2E-16	***	1.5147	0.0384	39.4252	2.2E-16	***
Adj. R-squared/F-statistic	0.8104	/3062.37 on 2 and 714 DF, p-value: < 2.22e-16				0.6539	/941,048 on 2 and 495 DF, p-value: < 2.22e-16			
model results	oneway individual effects first-difference model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−10.8944	−1.1435	−0.0567	1.0563	9.3783	−9.3996	−2.0465	−0.0902	2.0607	9.1499
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
price	−1.3904	0.2413	−5.7631	1.348E-08	***	−0.8427	0.1441	−5.8467	1.051E-08	***
gdp	1.2262	0.0368	33.3099	2.2E-16	***	1.4925	0.0563	26.5145	2.2E-16	***
Adj. R-squared/F-statistic	0.7911	/1093,74 on 2 and 575 DF, p-value: < 2.22e-16				0.6636	/392.642 on 2 and 395 DF, *p*-value: < 2.22e-16			

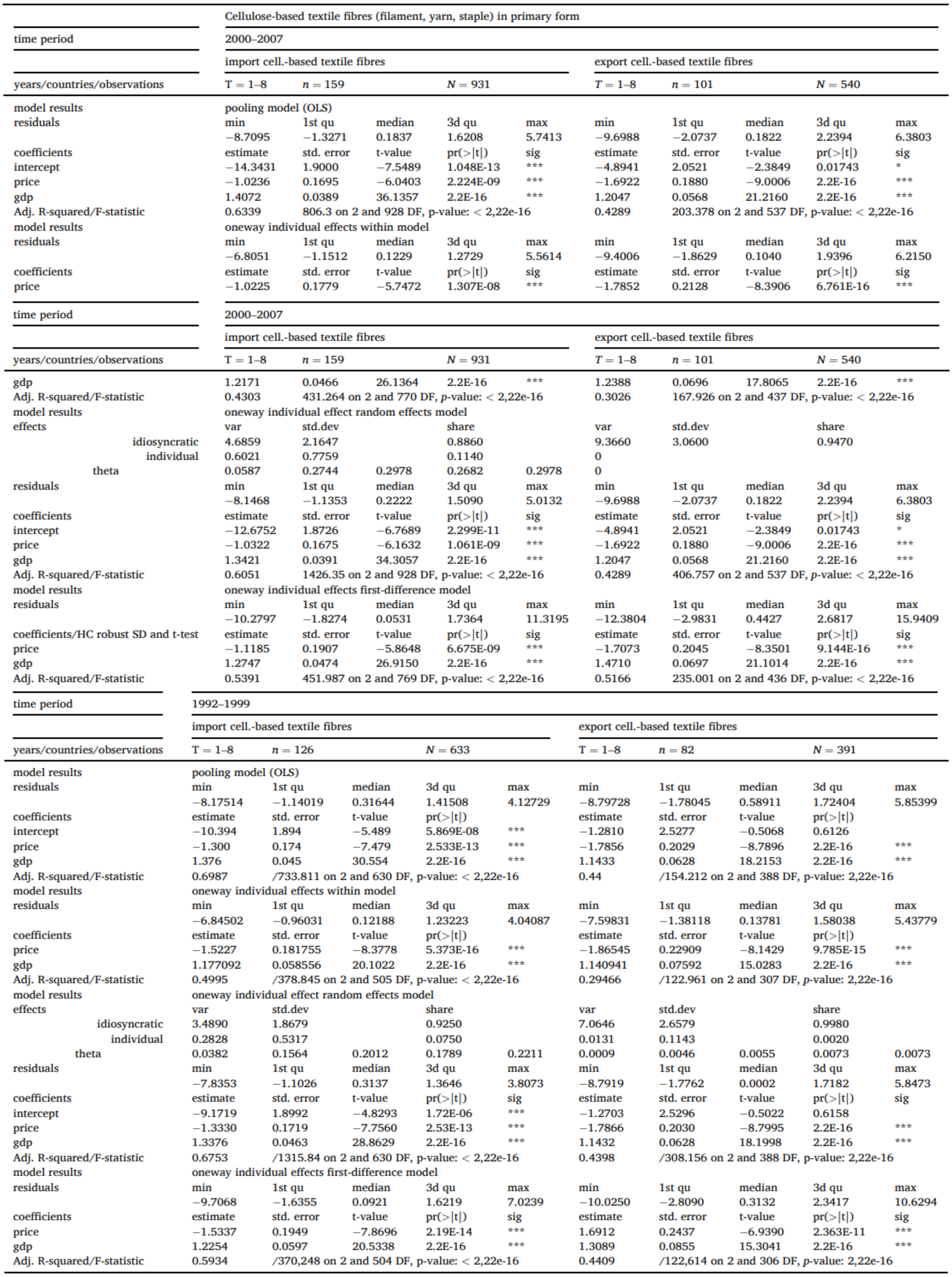
Note: results for export supply and import demand models obtained with four model types (pooling, fixed effects, first-difference, and random effects estimator) including standard errors, t-values, probabilities and significance levels as well as F-statistics and adjusted R-Square to indicate explanatory power of the respective model. Model variables are con~dwuv+gdp, T refers to the years, n to the number of countries, and N to the number of observations.

Table 3.10 Cellulose-based textile fibres income and price elasticity estimations



	Cellulose-based textile fibres (filament, yarn, staple) in primary form									
time period	2000–2015									
	import cell.-based textile fibres					export cell.-based textile fibres				
years/countries/observations	T = 1–16	*n* = 172		*N* = 1869		*T* = 1–16	*n* = 115		*N* = 1055	
model results	pooling model (OLS)									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−10.3535	−1.4211	0.1817	1.8544	5.9795	−10.1739	−2.1162	0.1919	2.2820	6.7638
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	−12.3614	1.3787	−8.9657	2.2E-16	***	−4.7301	1.5933	−2.9688	3.06E-03	**
price	−1.2013	0.1520	−9.9855	2.2E-16	***	−1.6959	0.1172	−14.4711	2.2E-16	***
gdp	1.3791	0.0299	46.1968	2.2E-16	***	1.1837	0.0424	27.9217	2.2E-16	***
Adj. R-squared/F-statistic	0.5922	/1357,25 on 2 and 1866 DF, *p*-value: < 2,22e-16				0.4181	/379.721 on 2 and 1052 DF, p-value: < 2,22e-16			
model results	oneway individual effects within model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−10.7409	−1.2503	0.1097	1.5016	6.5087	−9.9564	−1.8803	0.1144	2.0944	6.7574
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	−1.2696	0.1143	−11.1090	2.2E-16	***	−1.6239	0.1227	−13.2350	2.2E-16	***
gdp	1.1738	0.0327	35.9130	2.2E-16	***	1.1838	0.0460	25.7250	2.2E-16	***
Adj. R-squared/F-statistic	0.4421	/826.604 von 2 and 1695 DF, p-value: < 2,22e-16				0.3364	/325.186 on 2 and 938 DF, p-value: < 2,22e-16			
model results	oneway individual effect random effects model									
effects	var	std.dev		share		var	std.dev		share	
idiosyncratic	5.7890	2.4060		0.9410		9.4470	3.0740		1.0000	
individual	0.3658	0.6048		0.0590		0				
theta	0.0302	0.2458	0.2716	0.2948	0.2948	0				
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−10.4473	−1.3276	0.1526	1.7553	5.5460	−10.1739	−2.1162	0.1919	2.2820	6.7638
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	−10.3569	1.3335	−7.7668	2.2E-16	***	−4.7301	1.5933	−2.9688	3.06E-03	**
price	−1.2255	0.1155	−10.6147	2.2E-16	***	−1.6959	0.1172	−14.4711	2.2E-16	***
gdp	1.3068	0.0293	44.6667	2.2E-16	***	1.1837	0.0424	27.9217	2.2E-16	***
time period	2000–2015									
	import cell.-based textile fibres					export cell.-based textile fibres				
years/countries/observations	T = 1–16	*n* = 172		*N* = 1869		*T* = 1–16	*n* = 115		*N* = 1055	
Adj. R-squared/F-statistic	0.5720	/2498,79 on 2 and 1866 DF, p-value: < 2,22e-16				0.4181	/759.443 on 2 and 1052 DF, p-value: < 2,22e-16			
model results	oneway individual effects first-difference model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−12.6277	−2.1758	−0.0109	2.0509	11.8101	−12.2877	−3.2403	0.2328	3.0017	14.8214
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	−1.4850	0.1279	−11.6126	2.2E-16	***	−1.4193	0.1395	−10.1755	2.2E-16	***
gdp	1.2015	0.0382	31.4273	2.2E-16	***	1.3928	0.0600	23.2313	2.2E-16	***
Adj. R-squared/F-statistic	0.4884	/810,566 on 2 and 1694 DF, p-value: < 2,22e-16				0.4428	/374.074 on 2 and 937 DF, *p*-value: < 2,22e-16			
time period	2008–2015									
	import cell.-based textile fibres					export cell.-based textile fibres				
years/countries/observations	T = 1–8	*n* = 160		*N* = 938		T = 1–8	n = 100		*N* = 515	
model results	pooling model (OLS)									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−10.2599	−1.5253	0.1152	2.1132	5.7085	−9.6821	−2.0271	0.2105	2.0669	6.7870
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	−11.4422	1.9151	−5.9746	3.275E-09	***	−6.5494	2.9606	−2.2122	0.0274	*
price	−1.3019	0.1739	−7.4870	1.627E-13	***	−1.5992	0.1960	−8.1596	2.621E-15	***
gdp	1.3689	0.0375	36.4611	2.2E-16	***	1.2051	0.0818	14.7358	2.2E-16	***
Adj. R-squared/F-statistic	0.5589	594.714 on 2 and 935 DF, p-values <2,22e-16				0.4182	185.72 on 2 and 512 DF, *p*-value: < 2,22e-16			
model results	oneway individual effects within model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−9.9552	−1.3807	0.0628	1.5004	6.1803	−9.1712	−1.7762	0.0342	1.9520	6.9275
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	−1.4754	0.1739	−8.4864	2.2E-16	***	−1.5224	0.2179	−6.9866	1.134E-11	***
gdp	1.1337	0.0518	21.8883	2.2E-16	***	1.1921	0.0892	13.3638	2.2E-16	***
Adj. R-squared/F-statistic	0.3268	307.948 on 2 and 776 DF, p-value: < 2,22e-16				0.2446	133.734 on 2 and 413 DF, *p*-value: < 2,22e-16			
model results	oneway individual effect random effects model									
effects	var	std.dev		share		var	std.dev		share	
idiosyncratic	6.9040	2.6275		0.9700		9.4090	3.0670		1.0000	
individual	0.2160	0.4648		0.0300		0				
theta	0.0153	0.0824	0.1057	0.1057	0.1057	0				
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−10.2040	−1.4840	0.1190	2.0860	5.4260	−9.6821	−2.0271	0.2105	2.0669	6.7870
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	−10.5623	1.9048	−5.5452	3.821E-08	***	−6.5494	2.9606	−2.2122	0.0274	*
price	−1.1327	0.1700	−7.8049	1.59E-14	***	−1.5992	0.1960	−8.1596	2.621E-15	***
gdp	1.3417	0.0381	35.2598	2.2E-16	***	1.2051	0.0818	14.7358	2.2E-16	***
Adj. R-squared/F-statistic	0.5387	1096.18 on 2 and 935 DF, p-values <2,22e-16				0.4182	371.44 on 2 and 512 DF, p-value: < 2,22e-16			
model results	oneway individual effects first-difference model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−12.9027	−2.3629	−0.0520	2.4339	12.2911	−12.3928	−3.4081	−0.0169	3.1235	13.7238
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	−1.6842	0.1870	−9.0086	2.2E-16	***	−1.1772	0.2381	−4.9450	1.11E-06	***
gdp	1.1177	0.0592	18.8868	2.2E-16	***	1.2904	0.1068	12.0804	2.2E-16	***
Adj. R-squared/F-statistic	0.4432	310,247 on 2 and 775 DF, p-value: < 2,22e-16				0.3742	124.761 on 2 and 412 DF, p-value: < 2,22e-16			

Table 3.10 (continued)



	Cellulose-based textile fibres (filament, yarn, staple) in primary form									
time period	2000–2007									
	import cell.-based textile fibres					export cell.-based textile fibres				
years/countries/observations	T = 1–8	*n* = 159		*N* = 931		*T* = 1–8	*n* = 101		*N* = 540	
model results	pooling model (OLS)									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−8.7095	−1.3271	0.1837	1.6208	5.7413	−9.6988	−2.0737	0.1822	2.2394	6.3803
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	−14.3431	1.9000	−7.5489	1.048E-13	***	−4.8941	2.0521	−2.3849	0.01743	*
price	−1.0236	0.1695	−6.0403	2.224E-09	***	−1.6922	0.1880	−9.0006	2.2E-16	***
gdp	1.4072	0.0389	36.1357	2.2E-16	***	1.2047	0.0568	21.2160	2.2E-16	***
Adj. R-squared/F-statistic	0.6339	806.3 on 2 and 928 DF, p-value: < 2,22e-16				0.4289	203.378 on 2 and 537 DF, p-value: < 2,22e-16			
model results	oneway individual effects within model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−6.8051	−1.1512	0.1229	1.2729	5.5614	−9.4006	−1.8629	0.1040	1.9396	6.2150
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	−1.0225	0.1779	−5.7472	1.307E-08	***	−1.7852	0.2128	−8.3906	6.761E-16	***
time period	2000–2007									
	import cell.-based textile fibres					export cell.-based textile fibres				
years/countries/observations	T = 1–8	*n* = 159		*N* = 931		*T* = 1–8	*n* = 101		*N* = 540	
gdp	1.2171	0.0466	26.1364	2.2E-16	***	1.2388	0.0696	17.8065	2.2E-16	***
Adj. R-squared/F-statistic	0.4303	431.264 on 2 and 770 DF, *p*-value: < 2,22e-16				0.3026	167.926 on 2 and 437 DF, *p*-value: < 2,22e-16			
model results	oneway individual effect random effects model									
effects	var	std.dev		share		var	std.dev		share	
idiosyncratic	4.6859	2.1647		0.8860		9.3660	3.0600		0.9470	
individual	0.6021	0.7759		0.1140		0				
theta	0.0587	0.2744	0.2978	0.2682	0.2978	0				
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−8.1468	−1.1353	0.2222	1.5090	5.0132	−9.6988	−2.0737	0.1822	2.2394	6.3803
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	−12.6752	1.8726	−6.7689	2.299E-11	***	−4.8941	2.0521	−2.3849	0.01743	*
price	−1.0322	0.1675	−6.1632	1.061E-09	***	−1.6922	0.1880	−9.0006	2.2E-16	***
gdp	1.3421	0.0391	34.3057	2.2E-16	***	1.2047	0.0568	21.2160	2.2E-16	***
Adj. R-squared/F-statistic	0.6051	1426.35 on 2 and 928 DF, p-value: < 2,22e-16				0.4289	406.757 on 2 and 537 DF, *p*-value: < 2,22e-16			
model results	oneway individual effects first-difference model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−10.2797	−1.8274	0.0531	1.7364	11.3195	−12.3804	−2.9831	0.4427	2.6817	15.9409
coefficients/HC robust SD and t-test	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	−1.1185	0.1907	−5.8648	6.675E-09	***	−1.7073	0.2045	−8.3501	9.144E-16	***
gdp	1.2747	0.0474	26.9150	2.2E-16	***	1.4710	0.0697	21.1014	2.2E-16	***
Adj. R-squared/F-statistic	0.5391	451.987 on 2 and 769 DF, p-value: < 2,22e-16				0.5166	235.001 on 2 and 436 DF, p-value: < 2,22e-16			
time period	1992–1999									
	import cell.-based textile fibres					export cell.-based textile fibres				
years/countries/observations	T = 1–8	*n* = 126		*N* = 633		T = 1–8	*n* = 82		*N* = 391	
model results	pooling model (OLS)									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−8.17514	−1.14019	0.31644	1.41508	4.12729	−8.79728	−1.78045	0.58911	1.72404	5.85399
coefficients	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
intercept	−10.394	1.894	−5.489	5.869E-08	***	−1.2810	2.5277	−0.5068	0.6126	
price	−1.300	0.174	−7.479	2.533E-13	***	−1.7856	0.2029	−8.7896	2.2E-16	***
gdp	1.376	0.045	30.554	2.2E-16	***	1.1433	0.0628	18.2153	2.2E-16	***
Adj. R-squared/F-statistic	0.6987	/733.811 on 2 and 630 DF, p-value: < 2,22e-16				0.44	/154.212 on 2 and 388 DF, p-value: 2,22e-16			
model results	oneway individual effects within model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−6.84502	−0.96031	0.12188	1.23223	4.04087	−7.59831	−1.38118	0.13781	1.58038	5.43779
coefficients	estimate	std. error	t-value	pr(>|t|)		estimate	std. error	t-value	pr(>|t|)	
price	−1.5227	0.181755	−8.3778	5.373E-16	***	−1.86545	0.22909	−8.1429	9.785E-15	***
gdp	1.177092	0.058556	20.1022	2.2E-16	***	1.140941	0.07592	15.0283	2.2E-16	***
Adj. R-squared/F-statistic	0.4995	/378.845 on 2 and 505 DF, p-value: < 2,22e-16				0.29466	/122.961 on 2 and 307 DF, *p*-value: 2,22e-16			
model results	oneway individual effect random effects model									
effects	var	std.dev		share		var	std.dev		share	
idiosyncratic	3.4890	1.8679		0.9250		7.0646	2.6579		0.9980	
individual	0.2828	0.5317		0.0750		0.0131	0.1143		0.0020	
theta	0.0382	0.1564	0.2012	0.1789	0.2211	0.0009	0.0046	0.0055	0.0073	0.0073
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−7.8353	−1.1026	0.3137	1.3646	3.8073	−8.7919	−1.7762	0.0002	1.7182	5.8473
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
intercept	−9.1719	1.8992	−4.8293	1.72E-06	***	−1.2703	2.5296	−0.5022	0.6158	
price	−1.3330	0.1719	−7.7560	2.53E-13	***	−1.7866	0.2030	−8.7995	2.2E-16	***
gdp	1.3376	0.0463	28.8629	2.2E-16	***	1.1432	0.0628	18.1998	2.2E-16	***
Adj. R-squared/F-statistic	0.6753	/1315.84 on 2 and 630 DF, p-value: < 2,22e-16				0.4398	/308.156 on 2 and 388 DF, p-value: 2,22e-16			
model results	oneway individual effects first-difference model									
residuals	min	1st qu	median	3d qu	max	min	1st qu	median	3d qu	max
	−9.7068	−1.6355	0.0921	1.6219	7.0239	−10.0250	−2.8090	0.3132	2.3417	10.6294
coefficients	estimate	std. error	t-value	pr(>|t|)	sig	estimate	std. error	t-value	pr(>|t|)	sig
price	−1.5337	0.1949	−7.8696	2.19E-14	***	1.6912	0.2437	−6.9390	2.363E-11	***
gdp	1.2254	0.0597	20.5338	2.2E-16	***	1.3089	0.0855	15.3041	2.2E-16	***
Adj. R-squared/F-statistic	0.5934	/370,248 on 2 and 504 DF, p-value: < 2,22e-16				0.4409	/122,614 on 2 and 306 DF, *p*-value: 2,22e-16			

Note: Results for export supply and import demand models obtained with four model types (pooling, fixed effects, first-difference, and random effects estimator) including standard errors, t-values, probabilities and significance levels as well as F-statistics and adjusted R-Square to indicate explanatory power of the respective model. Model variables are con~dwuv+gdp, T refers to the years, n to the number of countries, and N to the number of observations.

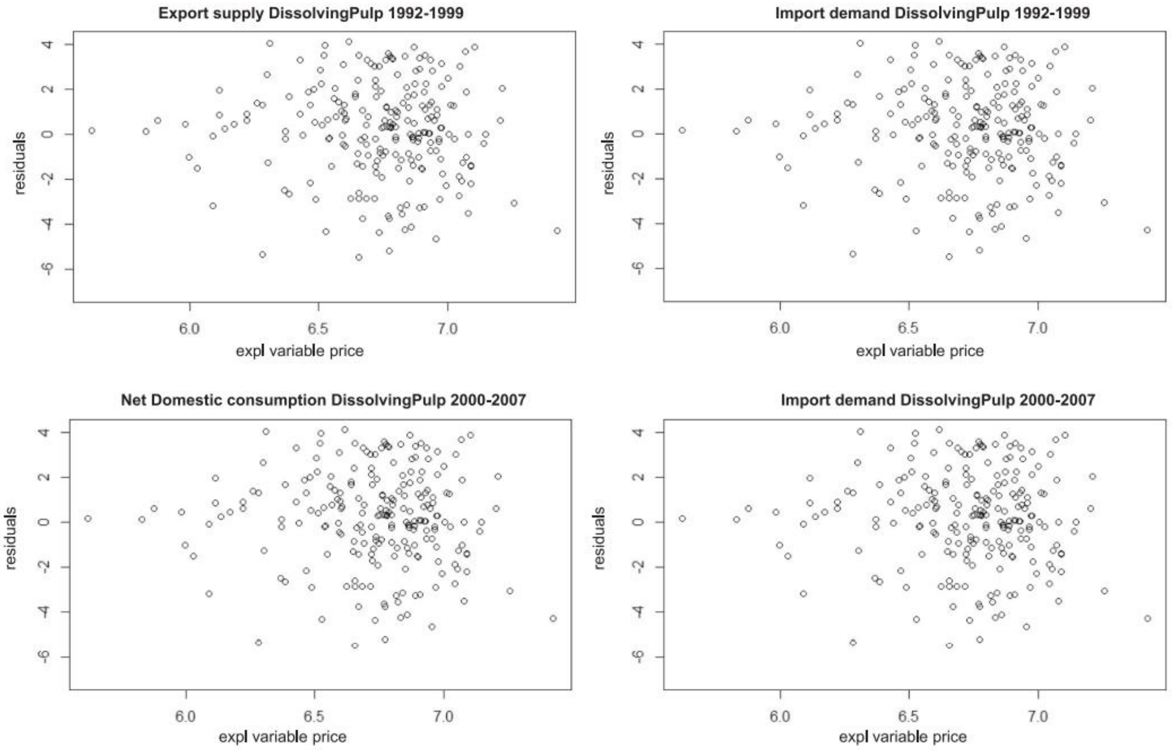


Figure 3.3 Inspection of residuals from dissolving pulp regression models against explanatory variable “price” to check for reverse causality problem due to endogeneity

4. Modelling Bioeconomy Scenario Pathways for the Forest Products Markets with Emerging Lignocellulosic Products

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4.1. Abstract

The forest-based sector plays diverse roles among the emerging bio-based industries. The goal of this study is to examine how forest product markets could develop in the face of a growing bioeconomy and which interdependencies occur between traditional and emerging forest-based sectors. Therefore, we analyze the development of dissolving pulp together with lignocellulose-based textile fibres and chemical derivatives in a partial equilibrium model. For this purpose, we extend the product structure of the Global Forest Products Model (GFPM) and analyze three different bioeconomy scenarios from 2015 to 2050. The simulation results show that, in a scenario where the world is changing toward a sustainable bio-economy, wood consumption patterns shift away from fuelwood (−30% by 2050) and classical paper products (−32% by 2050) towards emerging wood-based products. In this context, the dissolving pulp subsector could outpace the continuously shrinking paper pulp subsector by 2050. To develop in this way, the dissolving pulp subsector mainly uses released resources from the decreasing paper pulp production. Simultaneously, wood-based panels are finding increasing application (+196% by 2050) and thus are taking over potential markets for sawn wood, for which production growth remains limited. Our results also show that, until 2050, the production of many wood-based products will take place mainly in Asia instead of North America and Europe.

Keywords: dissolving pulp; forest sector modelling; SSP scenarios; bioeconomy; cellulose textile fibres; global forest product markets

4.2. Introduction

Today, the shift from a petroleum-based to a more bio-based and sustainable industry is not primarily a matter of the (looming) depletion of fossil resources, but rather the response to demands from an increasingly ecologically conscious society. Among the bio-based resources, lignocellulosic biomass from wood is both an abundant and a very versatile raw material [1]. Wood serves to satisfy many needs of daily life, e.g., as a fuel for power and heating, or as input for the construction, furniture, paperboard, textile, and chemical industries. This lets the forest-based sector play diverse roles in a growing bioeconomy [2]. Former studies have shown that the production of forest products is demand-driven and influenced by technological developments and input demands from wood consuming sectors [3]. Proceeding digitalization decreases the demand for graphic papers at the same as the packaging industry is growing due to increasing online shop sales (the share of packaging paper on total paper production increased from 50% in 2008 to 59% in 2018; [4]). Wood-based panel production catches up to sawn wood production (the production of wood-based panels developed from 178 million t in 2000 to 387 million t in 2015, while the sawn wood production increased from 385 million t to 447 million t in the same time; [4]), and niche products like the ligno-cellulosic textile fibres or chemical derivatives gain more and more importance as substitutes for petro-based products [5]. The climate change debate and associated consequences propel the demand for sustainable forest products [6]. Since wood is a multifunctional raw material, the forest sector faces various and potentially conflicting demands from different traditional and emerging wood-using sectors. At the same time, different industries continuously improve their production efficiency and introduce innovative product developments such as sandwich panels [7] or new product applications based on, e.g., dissolved lignocellulose.

At present, dissolved lignocellulose (hereinafter referred to as dissolving pulp) is mainly used as raw material for the production of lignocellulose-based derivatives and regenerated ligno-cellulosic fibres (during the production process of lignocellulosic textile fibres, derived cellulose is converted into a solid fabric as filaments or staples. Like synthetic fibres, they can be formed into many textures and properties.) [8]. Especially the textile industry is a growing consumer of fibers from regenerated lignocellulose. With increasing global population and income, the global textile fiber demand will also increase further. At present, cotton is the most important natural cellulose fibre for the production of textile fibres [9]. However, future cotton production is likely to slow down due to the limited availability of arable land, its negative environmental impacts, and contribution to GHG emissions [10]. The resulting gap in cellulosic fibre demand may be compensated for by lignocellulosic materials. This, in turn, could result in a significant growth of dissolving pulp demand [11]. In addition to the factors above, an emerging bio-based economy may further drive the demand for more sustainable cellulose chemical derivatives and fibres made from dissolving pulp. Considering the growing economic importance of lignocellulosic products, their inclusion in wood products market modelling seems to be important in order to analyze raw material allocation and intra-sectoral developments adequately. This step extends scientific computer-based equilibrium analysis and thus, foster well-informed decision making and policy advice.

In the light of the above, the goal of this study is to examine how forest product markets could develop in face of alternative bioeconomy scenarios, and the effects of the emergence of new – and maybe competing—values of wood in global forest product markets. Until now, no studies have been available investigating scenarios which include lignocellulosic materials from dissolving pulp in global forest product market modelling. Therefore, we embed the development of dissolving pulp, lignocellulosic chemical derivatives, and textile fibres within the context of a partial equilibrium model for wood product markets. This methodological enhancement makes it possible to model and analyze the interdependencies that may occur between traditional and emerging forest-based sectors within the transition of a petrol-based economy to a more sustainable bio-based economy.

This study is structured as follows: first, the modelling framework is illustrated with a short description of the applied model. Thereafter, the bioeconomy scenarios used for this study are introduced and the integration of emerging lignocellulose-based products into the model framework is described. Then, the results are presented and discussed. Finally, the main findings are summarized, and future research tasks outlined.

4.3. Materials and Methods

The use of economic equilibrium models is of great benefit to show long term interdependencies between economic, social, and technical developments, which humans can hardly foresee in their complexity. For this reason, the present study utilizes the Global Forest Products Model (GFPM,originally developed by Buongiorno et al. [12]). The GFPM is a spatial dynamic economic equilibrium model that simulates the development of the forest and wood product markets in the mid- and long run. In order to enhance projections and inferences drawn from forest products market modelling, the present study implements emerging lignocellulosic-based products into the model framework of the GFPM. Since this paper tries to analyze the potential of lignocellulosic-based products and the resulting impact on other wood-based products, we do not apply a model for the textile markets, which considers different types of fibres. However, such a model could be of great importance to explain the demand side for lignocellulose-based textile fibres in a competitive environment.

For the present study, the basic model version is enhanced and includes emerging ligno-cellulosic products (see Section 2.2). The purpose of this work is to assess alternative bioeconomy scenarios.

Each scenario bases on exogeneous model assumptions regarding the economic, demographic, and forest sector specific developments. For general economic and demographic developments, the present study orientates on the Shared Socioeconomic Pathways (SSP) as scenarios for country wise possible pathways of the GDP and population developments up to the year 2100 [13]. For forest sector related assumptions, this study refers to storylines made within the context of the German research project BEPASO (Bioeconomy pathways and societal transformation strategies). An overview will be introduced in Section 2.3.

4.3.1. GFPM

The Global Forest Products Model (GFPM) is a spatial dynamic economic equilibrium model designed to assess alternative forest sector developments under shifting market patterns, impacts of forest sector policies, or alternative forest management scenarios [14–16]. The model links wood product supply, manufacturing, consumption, and trade [17,18]. It simulates production, consumption, and trade volumes at the national to global level for 180 countries and 14 raw-, intermediate- and end products in competitive world markets [12,14]. The basis for our work is the enhanced version of the GFPM introduced by Schier et al. (2018) [19], which distinguishes 16 wood products. In addition to the original model version, industrial roundwood and sawnwood are split into two different products, while all subsequent commodities can be produced from a mix of coniferous and non-coniferous industrial roundwood. The resulting model structure for this study is depicted in Figure 4.1.

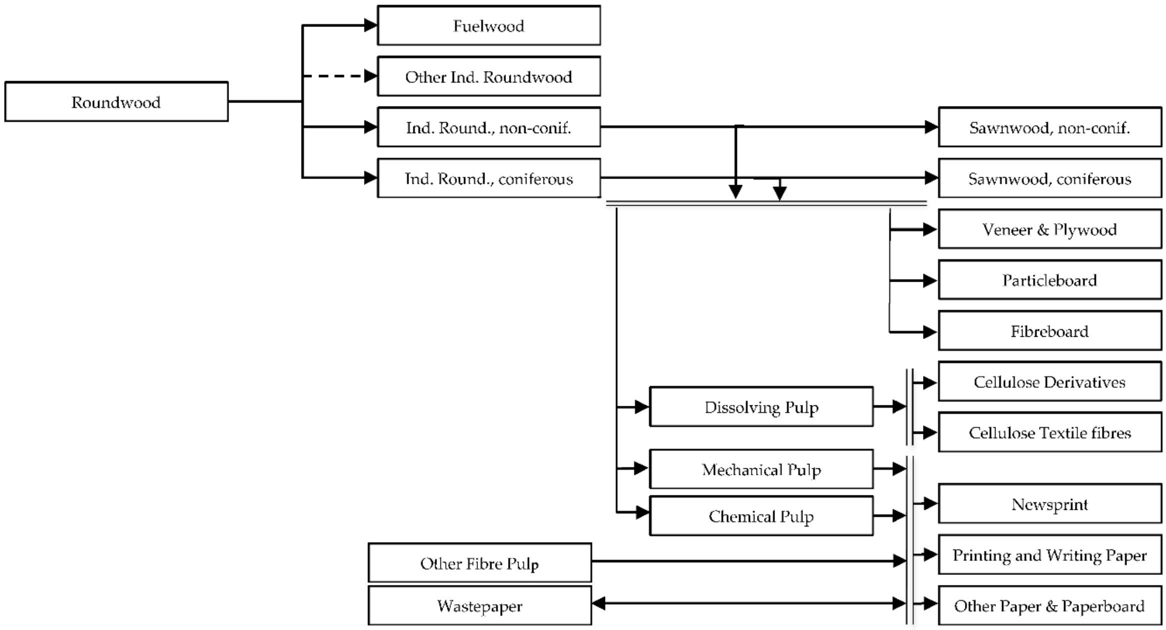

Figure 4.1 Suggested Model Structure and Transformation Processes in the GFPM. Note: Ind. Round. = Industrial Roundwood

The input data for this model specification come from FAO forestry statistics [4], the FAO Forest Global Resources Assessment (FRA) [20], and the World Bank [21]. The FAOSTAT provides global and country wise data for the production and trade of forest products, while the FRA reports data for forest area and stock changes. To be consistent with the BEPASO modeling approach, data on GDP and GDP per capita are taken from the World Bank's "World Development Indicators" for a period between 1992 and 2015, and from the World Bank's "Global Economic Prospects" [21] for GDP outlook for the period between 2016 and 2019.

4.3.2. Implementation of Lignocellulose-Based Products in the GFPM Framework

The enhancement of the GFPM framework in the present study addresses the endogenous integration of emerging values from wood to the value chain. For this purpose, we further extend the model structure of the GFPM as introduced by Schier et al. (2018) [19] from 16 to 19 products in order to remodel and analyze wood-product market and forest sector transformation.

Analogous to the existing intermediate products chemical and mechanical pulp, we implement dissolving pulp as an intermediate product in the GFPM. Both coniferous and non-coniferous wood are entirely suitable raw materials for the production of dissolving grade pulps. Lignocellulose-based chemical derivatives and textile fibres are added as two additional end products. Dissolving pulp is used as raw material to produce lignocellulosic chemical derivatives and textile fibres [8]. The structure of the adapted and enhanced version of the GFPM is given in Figure 4.1.

However, any change of the model structure and input data requires the reprogramming of the model calibration for input data harmonization [19]. The calibration of model input data prior to estimation of the base period strictly requires information on production and trade volumes of all products.

Thus, we need base year production and trade figures for the newly integrated products. Unfortunately, there is no freely accessible global database covering the national production volumes for lignocellulose-based chemical derivatives and textile fibres. However, the FAO reports global dissolving pulp production, import, and export data on country level [4]. Based on this data, the net domestic consumption of dissolving pulp can be calculated, which is, in turn, the source for the lignocellulose-based end products. Keeping this in mind, we collect data about import and export quantities of lignocellulose-based products from the UN Comtrade database [22]. We further collect data on the global production of lignocellulose-based textile fibers and chemical derivatives as well as country and regionally specific information [23–25]. We combine these data to estimate national production of lignocellulose-based products according to the following procedure (see Figure 4.2):

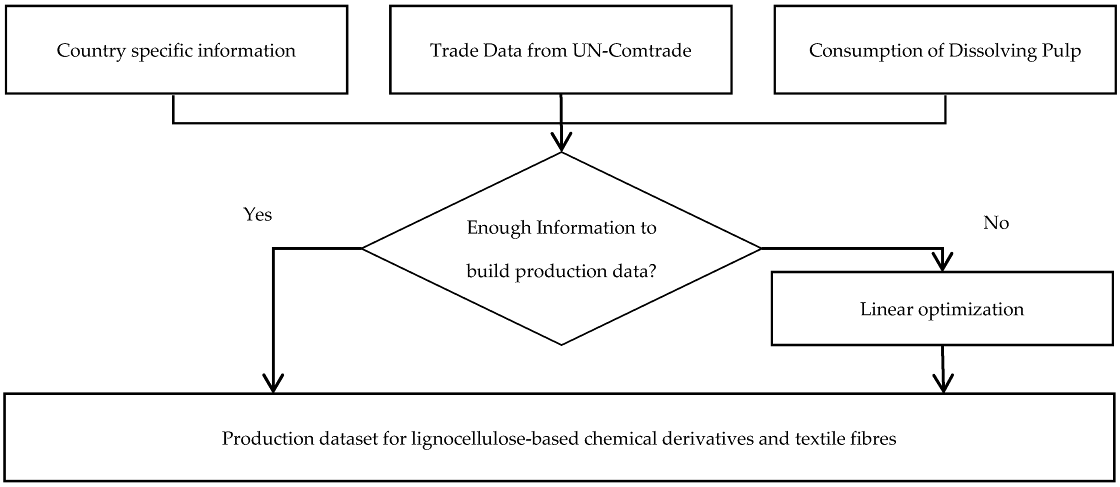

Figure 4.2 Scheme of production data generation for lignocellulose-based chemical derivatives and textile fibres

First, we assume that the entire dissolving pulp consumption is distributed among lignocellulose-based chemical derivatives and textile fibers. This implies that that no other products are made from dissolving pulp. Second, the country specific information allows the definition of rough production quantities for most important producer countries. Third, data about trade with lignocellulose-based products in combination with information about regional and global developments define minima and maxima bounds for the domestic production of lignocellulose-based chemical derivatives and textile fibres in countries for which no specific information are available. We use this information to allocate global production of lignocellulose-based products over all countries via linear programming. As a result, we receive a country-wise approximation for the use of domestic consumption of dissolving pulp for the production of lignocellulose-based derivatives and textile fibers. To obtain the production quantity of these products, the input quantity of dissolving pulp must be multiplied with a product and country specific manufacturing coefficient. For the production of cellulose chemical derivatives and textile fibres from dissolving pulp, we assume a manufacturing coefficient of one. Table 4.3 (see appendix) presents the country specific data used to build the linear programming for the domestic production of lignocellulose-based textile fibers in selected countries. Table 4.4 (see appendix) shows the results obtained from this procedure for the same countries.

Beside the base year production, consumption, and trade data, the GFPM depends on demand and supply elasticities as well as exogenous parameters that set the framework for the model behavior and developments during scenario simulations. Elasticities used for the present study are either taken from the latest versions of the GFPM [12] or from recent econometric studies for supply and demand in traditional forest markets [3] and for lignocellulose-based products [26].

4.3.3. Future Pathways for Bioeconomy Scenarios

Meaningful scenario simulations must build on plausible development paths, which we introduce in the following sections. In this study, we model three bioeconomy scenarios combining story lines elements from the SSP scenarios and the BEPASO project.

The subject of the BEPASO project was to develop alternative bio-economy pathways and social transformation strategies up to the year 2050. The scenarios were developed in an interactive participation process with stakeholders and citizens. The resulting scenarios were named: “Bioeconomy islands”, “Bioeconomy on the drip”, and “Bioeconomy change” [27]. To embed these BEPASO storylines into a macroeconomic framework, they were assigned to the scenarios of different SSP storylines [27].

The SSP scenarios describe five narratives for future developments and the accompanying driving forces [13]. In the present paper, we focus on the implementation of GDP and GDP per capita developments from three (SSP1, SSP2, SSP4) of the five SSP scenarios up to the year 2050 (see Table 4.1). For this purpose, we use data from the SSP data base (within the SSP Data base we used data from the OECD Env-Growth model for GDP and population) on the projection of GDP [28] and population development [29] for more than 200 countries. The data are the key assumptions to build a consistent and global socioeconomic framework for the scenario simulation in this paper.

Table 4.1 Assumptions on future forest sector developments (displayed as global averages).

	Country Related (GDP per Capita [1])		Forest Products Related (Technological Change [2])		Global Growth of Forest Stock from 2015 to 2050	
High sustainability scenario	SSP1	3.655%	Bioeconomy Change	1.586%	Bioeconomy Change	27.707%
Mid sustainability scenario	SSP4	2.887%	Bioeconomy Islands	0.378%	Bioeconomy Islands	28.462%
Low sustainablity scenario	SSP2	3.018%	Bioeconomy on the Drip	0.042%	Bioeconomy on the Drip	27.945%

Note: [1] Global mean growth rate per year between 2015 and 2050 as calculated by SSP [28,29]; [2] growth rate of technological efficiency per year as global mean over all products; Technological change is calculated separately for each product in 180 countries via the GFPM to catch up with the BEPASO storylines

Basically, in the “Bioeconomy on drip” scenario, biomass plays a minor role as a raw material in the global industrial production process. Globally, subsidies and customs tariffs either remain constant or increase due to trade disputes. At the same time, no real technological breakthrough regarding green innovations takes place. Thus, the world only experiences a slight increase in the efficiency of resource use. This scenario is assigned to the SSP scenario 2 “Middle of the Road” [30], which describes the continuation of past dynamics. In the other two scenarios, the demand for biomass for non-nutrition purposes is growing. The main aspects for the modelling approach, beside GDP and population development from the SSP 2, are the relative slow technological progress mirrored in only slightly decreasing input–output ratio of raw wood in the transformation process throughout the wood-based sectors, constant to increasing trade barriers and a constant energetic use of wood compared to present levels. Several other side aspects of this scenario can be found at [27].

In the scenario “Bioeconomy islands”, biomass is mainly used to produce energy in order to replace a fossil-based economy. Here, technological developments occur but take off primarily in high- and middle-income countries. This scenario is aligned with SSP scenario 4 “Inequality—A Road Divided” [31], which describes social and economic inequality between regions where environmental and sustainable sound development is only a priority for a few affluent regions. The main aspects for the modelling approach, beside GDP and population development from the SSP 4, are the inequality of technological progress in high- and middle- to low-income countries, decreasing trade barriers, and an increasing energetic use of wood. Several other side aspects of this scenario can be found at [27].

In the “Bioeconomy change” scenario, biomass is mainly used as input to produce diverse industrial and everyday products. This development goes along with a globally efficient exchange of research and development activities and breakthroughs in green technologies. In this scenario, the world benefits from an optimization of resource use. This scenario is assigned to the SSP scenario 1 “Sustainability—Taking the Green Road” [32] where global cooperation goes along with an increasing focus on environmental and forest protection as well as a shift in human dietary and energy production. The main aspects for the modelling approach, beside GDP and population development from the SSP 1, are the fast and global technological progress, a concentration for regional production, and a decreasing energetic use of wood. Several other side aspects of this scenario can be found at [27]. Table 4.1 gives a brief summary of the exogenous macroeconomic and forest related development assumptions from these bioeconomy scenarios for the implementation into the enhanced GFPM. These assumptions include, among others, the development of GDPs and GDPs p.c., fuel wood demand, and technological changes over time. A more detailed summary on the assumptions on future forest sector developments for the top ten producers of industrial roundwood is given in Table 4.5 (see appendix).

4.4. Results

In the following, we present selected results from the simulation of the three bioeconomy scenarios with the enhanced version of the GFPM. We refer to the bioeconomy scenarios according to the nomenclature of the BEPASO storylines: “Bioeconomy on the Drip” (“Drip”) as description for less sustainable global developments, “Bioeconomy Islands” (“Islands”) for a partially change into a more bio-based and sustainable world, and “Bioeconomy Change” (“Change”) for a global shift to a sustainable bioeconomy. In general, we observe a larger increase in total wood consumption in the two scenarios promoting a progressive and bio-based development of the future economy (“Change” and “Islands”), while the total wood consumption in the “Drip” scenario increases only slightly on global level. However, the way wood is used differs between the scenarios. Table 4.2 summarizes the main results.

Table 4.2 Scenario results from the simulation of three alternative bioeconomy scenarios.

Commodity	Unit	Global Consumption 2015	Global Consumption in 2050 and Growth from 2015 to 2050 in Percentage					
			Drip Scenario		Islands Scenario		Change Scenario	
Roundwood	mil m^3	3833.40	4332.87	13.0%	4812.13	25.5%	5479.08	42.9%
Fuelwood	mil m^3	1847.42	2400.32	29.9%	2394.08	29.6%	1265.06	−31.5%
Industrial Roundwood	mil m^3	1832.62	1734.66	−5.3%	2219.77	21.1%	4019.40	119.3%
Industrial Roundwood C	mil m^3	1066.82	996.38	−6.6%	1199.33	12.4%	2252.11	111.1%
Industrial Roundwood NC	mil m^3	765.82	801.21	4.6%	1163.41	51.8%	1767.30	130.8%
Sawnwood	mil m^3	464.84	456.61	−1.8%	527.54	13.5%	545.06	17.3%
Sawnwood C	mil m^3	328.95	318.24	−3.3%	369.99	12.5%	365.44	11.1%
Sawnwood NC	mil m^3	135.88	138.36	1.8%	157.55	15.9%	179.62	32.2%
Wood-based panels	mil m^3	420.71	433.86	3.1%	676.10	60.7%	1243.24	195.5%
Fiberboard	mil m^3	128.35	132.29	3.1%	226.84	76.7%	508.40	296.1%

Particle Board	mil m^3	113.15	112.53	−0.6%	144.76	28.0%	214.52	89.6%
Veneer Sheets and Plywood	mil m^3	179.20	189.04	5.5%	304.50	69.9%	520.32	190.4%
Paper pulp	mil t	174.36	186.32	6.9%	149.67	−14.2%	122.45	−29.8%
Newsprint	mil t	26.70	27.82	4.2%	22.85	−14.5%	14.60	−45.3%
Other Paper and Board	mil t	282.56	322.51	14.1%	304.47	7.6%	212.66	−24.7%
Printing and Writing Paper	mil t	103.44	115.95	12.1%	85.93	−17.1%	60.26	−41.8%
Dissolving Pulp	mil t	6.79	7.26	6.9%	81.33	1097.5%	217.27	3099.1%
Cellulose derivatives	mil t	2.00	2.28	14.0%	11.56	477.4%	10.38	418.3%
Cellulose regeneratives	mil t	4.94	5.47	10.7%	73.58	1388.4%	207.06	4088.9%

The global energetic use of wood is decreasing from 2015 to 2050 in the “Change” scenario (by −31.52%) and increasing in the “Drip” (by −29.59%) and “Islands” (by −29.59%) scenarios. On the other hand, the global material use of wood is increasing in “Change” (by +119.33%) and “Islands” (by +21.06%) scenarios from 2015 to 2050, while it is decreasing in the “Drip” scenario (by −5.35%). Counterbalancing these developments, changes in total roundwood removals amount to +13.0%, +25.5%, and +42.9% in the “Drip”, “Island”, and “Change” scenario, respectively. This is in line with the BEPASO storylines described above. Increasing demand for industrial roundwood results mainly from demand shifts in the further processed wood products. Especially the “Change” scenario is driven by an increasing demand for wood-based panels (+195.51% compared to 2015) and dissolving pulp (+3099.12% compared to 2015) in 2050. At the same time, the paper consumption in this scenario drops by −30.33% between 2015 and 2050. This reduces the consumption of wood-based pulps as input in paper production by −34.30%.The increasing material use of wood until 2050 in the “Island” scenario is mainly driven by increasing demand for dissolving pulp (+1097.49%) and wood-based panels (+60.72%), while simultaneously the paper pulp, and thus paper production consumption, is decreasing (−14.84%) within this scenario. The nearly constant material use of wood in the “Drip” scenario results mainly from near constant demand for sawnwood (−1.77%), wood-based panels (+3.13%), and dissolving pulp (+6.91%).

4.5. Discussion

In the following, we will discuss the scenario results. Depending on the scenario, the global roundwood production in this study was calculated to lay between 4.3 and 5.5 billion m^3 per year. However, there are outlook studies that calculate global roundwood production scenarios, of which some show even stronger increases, e.g., [33] where the global roundwood production lay between 3.6 and 11.2 billion m^3 in 2060. Even if we would assume that the roundwood production would follow a linear trend, in 2050, it would lay between 4.7 billion m^3 (trend 2000–2019) and 5.8 billion m^3 (trend 2015–2019) (own calculation based on [4]). Therefore, we conclude that the future roundwood production as calculated in the present study seems to be feasible.

In 2015, the global production of dissolving pulp amounted to 7 million tons, while the global production of wood-based pulp for paper and paperboard amounted to 178 million tons [4]. In our scenario simulations, the dissolving pulp production increases up to 217 million tons within the next 35 years (see Figure 4.3). This development would indicate that the dissolving pulp sector could climb out of its current niche and become a relevant player within the forest-based industries. However, this development depends on the external scenario setting over the coming decades. In a scenario where the growth of a bioeconomy stagnates (“Drip” scenario), the share of the dissolving pulp sector in overall wood-based pulp (i.e., paper and dissolving pulp) output would stay constant, while in the more sustainable “Island” scenario the share rises to 35% in 2050. In the “Change” scenario, the production volumes of the dissolving pulp would exceed the production volumes of paper pulp (see Figure 4.3) and account for 64% of total wood-based pulp production. Between 2008 and 2018, the mean annual growth rate of the global dissolving pulp production was 10% (own calculation based on [4]). In order to reach the global production level of 81 million tons simulated in the “Island” scenario by 2050, a mean annual production growth of 6.9% would be required. Vice versa, a global production level of 217 million tons of dissolving pulp in 2050 implies a mean annual production growth of 9.8%. Even though we observed such a dynamic growth during the last decade, its continuation is closely related to the natural textile fibre markets, which in turn depend highly on GDP and Population developments [34]. However, the long-term projection of the currently dynamic development and limits of these markets for another three decades is almost impossible. Therefore, the results of this study should be interpreted as potential input from forest product markets to the textile fibre markets. This, especially as we know that the ongoing growth path of the dissolving pulp sector in the “Change” scenario, seems not to be in line with the expected limits of consumption in its long-term product cycle. Here, a refinement of exogenous long-term parameters within the model frameworks should be considered for future works.

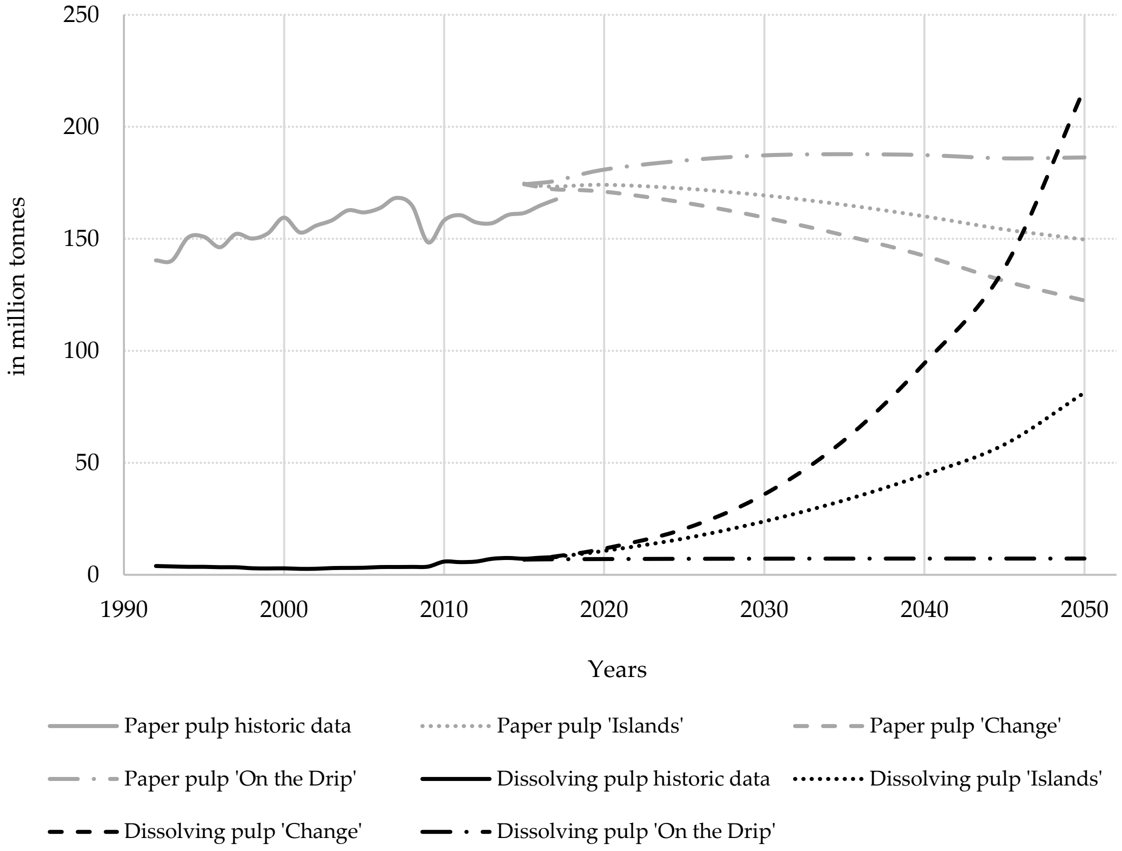

Figure 4.3 Paper pulp and dissolving pulp production globally.

In light of sector-specific projections for future textile fibre demand, we compare our results with other forecasting studies. In this context, the International Cotton Advisory Committee [35] projects a world fibre demand of 121 million tons for the year 2025, while, according to Textile World, the demand for textile fibres could reach 125 million tons [36] in 2030. In 2018, the share of lignocellulosic fibres in the total fibre mix accounted for 6.2% [37]. Thus, and if this fibre mix does not change over the next decade, the demand for ligno-cellulosic fibres would hover around 7.5 million tons in 2030 and thus be in line with the results we obtain with the “Drip” scenario.

In the “Island” and the “Change” scenarios, the production of lignocellulosic fibres reaches 24 million tons and 31 million tons, in 2030, respectively. We would need a growing share of lignocellulosic fibres in the total fibre mix from currently 6.2% to 19% in in order to reach the simulated production level in the “Island” Scenario. In the same manner, the share of lignocellulosic fibres had to grow to 25% in order to reach the production level of roughly 31 million tons of lignocellulosic fibre simulated in the "Change" scenario.

However, due to technological developments in wood processes that reduce the required wood input and the expected level of digitalization in production processes, the global increases in dissolving pulp production are not negatively correlated to the sawn wood and wood-based panels sectors in our simulations. While we observe that the global production of sawn wood only changes to a minor extent, the global production of wood-based panels even increases compared to the levels of 2015 in the "Change" and "Island" scenarios. Nevertheless, the increasing demand for lignocellulose-based textile fibers and the assumption that regional production will become more and more important (as described in "Change" and "Island" story lines), lead, in our simulations, to a shift in the production of dissolving pulp from North America and Europe to Asia (see Figure 4.4) until 2050. Practically, this would lead to decreasing importance of North America and Europe in global dissolving pulp markets. Today, Asia is the biggest importer of dissolving pulp, where it is mainly used for the production of lignocellulosic textile fibres, while North America and Europe are the biggest exporter of dissolving pulp [4]. Actually, global players of the industry invest in the establishment of new plants in Asia, which should lead to an expansion of production facilities for dissolving pulp in this region. In order to maintain or even increase its market share, North America and Europe would, e.g., have to concentrate on the development of new products from lignocellulose-based derivatives, like bioplastics or the investment in local textile industries rather than the export to Asia.

Similar shifts can be observed for several other forest products, too. Today, Asia is a net importer of roundwood, sawn wood, as well as paper and paperboard, while North America and Europe are net exporters for these product groups [4]. Our assessment suggests that, until 2050, the production of many wood-based products will take place directly in Asia instead of being imported from other continents such as North America and Europe. The shift in global production pattern is displayed in Figure 4.4. The figure shows that most product categories in nearly all scenarios are affected by these changes. However, the magnitude of the shifts is product specific: for sawn wood or wood-based panels, it is in general weaker, as for dissolving pulp or industrial roundwood (see Figure 4.4). Especially with regard to industrial roundwood, we observe decreasing shares of global production across all continents except Asia, where the shares of global production are increasing.

Eventually, we will discuss some weaknesses of the present approach. This study builds on the use of a partial equilibrium model and underlying scenario assumptions. These approaches have several inherent limitations: First, a general limitation for this kind of modelling is that all input data for the model rely on historical developments. This led to the conclusion that the GFPM in structure and its parameters is not sensitive to possible structural changes or idiosyncratic shocks in future, because it is built to describe the past and current state of the world.

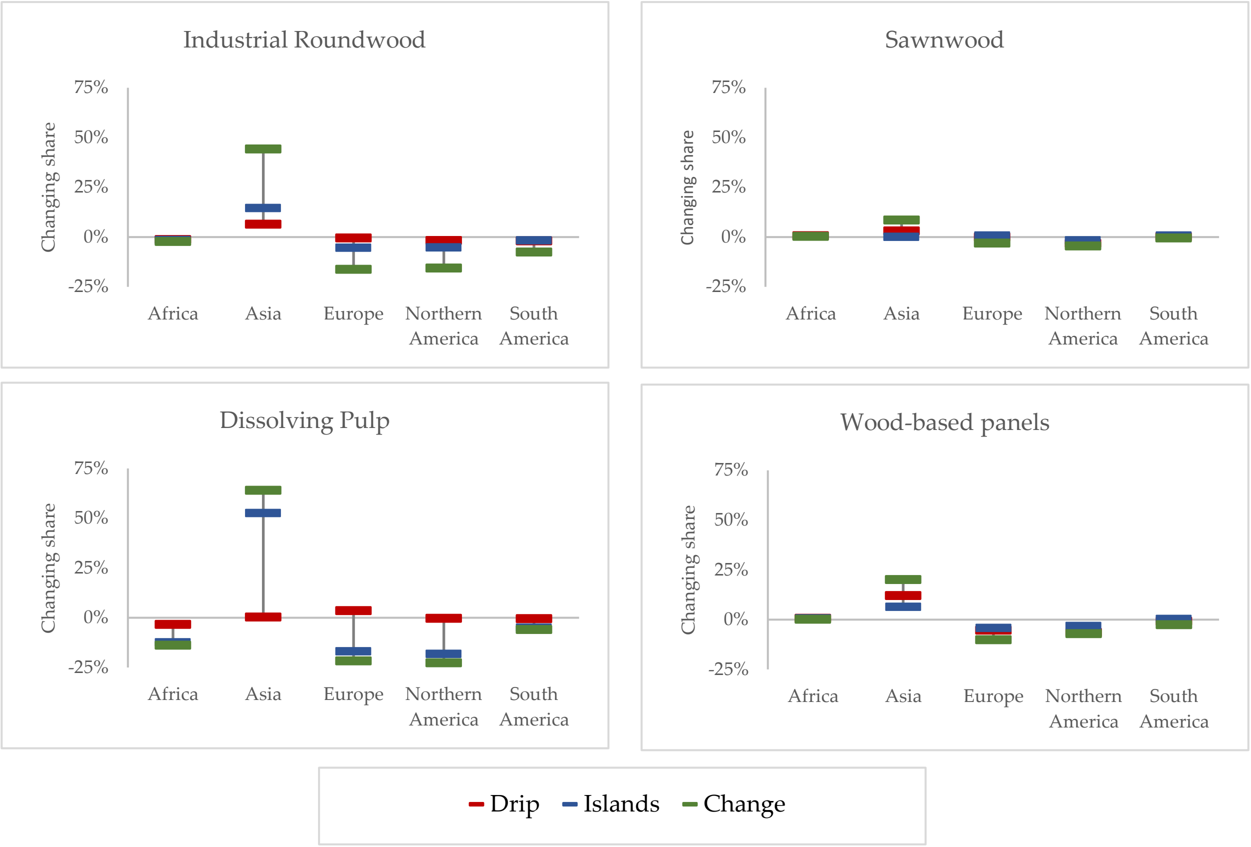

Figure 4.4 Change in the global market shares of a specific product between 2015 and 2050, by product

Note: market shares are calculated by dividing aggregated continental production of a product through the global production of the same product.

A second limitation of the present study is that the scenarios highly depend on assumptions about the future developments like population and GDP growth rates from the SSP scenarios and other exogenous changes from BEPASO storylines. A priori, it is not possible to judge about the probability and accuracy of the underlying scenario assumptions.

The last issue is that the GFPM does not model competing end product markets. Thus, the production of lignocellulose-based products in this study should be interpreted as a potential supply of these products and not as its end consumption.

Despite these limitations, we consider that the present approach allows for important insights into the possible future developments of wood product markets and thus, foster well-informed decision making and policy advice.

4.6. Conclusions

Traditional forest product markets are changing. Wood product market analysis needs to consider these changes by implementing emerging values from wood such as innovative usages of wood, like sandwich panels, or the emerging lignocellulose-based products like dissolving pulp. The present study did this by adapting global forest product modelling and implementing emerging lignocellulose-based products into the extended version of the GFPM. In such an enhanced forest sector modelling approach, the application of scenario-based analysis and the assessment of bioeconomy developments becomes possible for the first time. We analyze alternative bioeconomy pathways and their future market effects by integrating socioeconomic and technological developments from the SSP and BEPASO story lines up to 2050 into the framework of the enhanced version of the GFPM.

Our findings suggest that, if the world could change toward a sustainable bioeconomy, consumption of roundwood could shift from fuelwood or classical paper production towards more efficient production of wood-based panels or lignocellulose-based materials. However, we further suggest that such a development must be accompanied with technological changes to reduce the total amount of wood input in the final products. This would generate additional resources potentials for new wood-based products. In our scenario simulations, the growth of sawn wood production remains limited compared to the increasing importance of wood-based panels. Additionally, we found that the dissolving pulp subsector has the potential to outpace at least today's paper pulp subsector. Thereby, the increase in dissolving pulp production would not impact the resource base and production volumes of the sawn wood and wood-based panels sector compared to the level of 2015. This is, among other reasons, because ongoing digitalization and technological progress set free fibre resources that were formerly used for, e.g., paper production. In addition, non-coniferous wood is an entirely suitable raw material for the production of dissolving pulp. This reduces the competition for scarce coniferous resources needed for material wood processing.

We can conclude that in the case of the "Change" scenario, wood could play an increasingly important part in everyday life. Contrary to this, the results from the "Island" and "Drip" scenarios show that wood product markets could also adhere to the present pattern if the transformation is not fostered by socio-economic and technological development. The "Island" scenario further demonstrates that, in dependence of the market settings, wood could even increasingly be used for energetic purposes instead of being processed as input for material wood products.

The BEPASO project shows that the public is largely willing to move towards a sustainable and bio-based world [38]. However, one essential finding is that potential impacts of the transformation into a bio-based economy must be clearly communicated. Also important to support the social acceptance and make a bio-based economy happen is a public-oriented dialogue about the conditions and added values [38]. With this study in mind, we show that modelling is an important tool here. It makes long-term interactions visible and graphically tangible for people. Thereby, modelling helps to support reasonable and well-informed decision making in policies, since it shows interdependencies between markets, socio-economics and technological developments, especially in the long run, which humans can hardly foresee in their complexity.

This study is an initial step to include the emerging lignocellulose-based products into wood products market scenarios and analysis. While the dissolving pulp sector is well documented in terms of production, trade, and demand, we found considerable gaps in (freely) accessible information for lignocellulose-based textile fibres and, in particular, chemical derivatives. Future research needs to tackle this challenge and possibly provide refined scenario storylines and simulations on the development of these sectors in the context of global forest products market modelling.

Author Contributions: conceptualization: C.M. and F.S.; methodology: C.M. and F.S.; formal analysis: C.M. and F.S.; data curation: C.M. and F.S.; writing—original draft preparation: C.M. and F.S.; writing—review and editing: C.M. and F.S.; visualization: C.M. and F.S. All authors have read and agreed to the published version of the manuscript.

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4.7. Appendix

Table 4.3 Selection of country specific information about Cellulose-based textile fibers (TF).

Country	Country Specific Information about TF	Share of Global Production [25]	Dissolving Pulp (DP) Consumption in t [4]
Austria	400 kt Capacity [24]	9% in Europe	355,274.00
Germany	238 kt Production in 2011 [23]	9% in Europe	424,000.00
United King-	45 kt Capacity [24]	9% in Europe	48,468.00
China		66%	4,495,676.00
India		9%	828,875.00
Indonesia	Viscose Production 320 kt [24]	9%	360,286.00
Thailand		3%	141,129.00
USA		1% in North America	411,000.00
Canada		1% in North America	101,512.00
Japan		1%	167,629.00
World	5.6 mt Production in 2016 [39]	100%	8,251,431.00

Table 4.4 Dissolving pulp (DP) input for the production of lignocellulose-based textile fibers (TF) as a result of the linear optimization procedure for the year 2015.

Country	DP Input for TF in t	in % of Global
Austria	319,747	5.1%
Germany	251,651	4.0%
United Kingdom	45,075	0.7%
China	4,046,108	64.3%
India	580,213	9.2%
Indonesia	360,286	5.7%
Thailand	141,129	2.2%
USA	41,100	0.7%
Canada	10,151	0.2%
Japan	83,815	1.3%
World	6,294,984	100%

Table 4.5 Assumptions on future forest sector developments for the top ten producers of industrial roundwood (displayed as country specific averages).

Sceanrio	ISO Code	Country	GDPpC growth [1]	Tech-Change [2]	Forest Growth [3]
Bioeconomy Change	BRA	Brazil	3.14%	0.28%	0.21%
Bioeconomy Change	CAN	Canada	1.07%	0.91%	0.31%
Bioeconomy Change	CHN	China	4.99%	0.23%	1.79%
Bioeconomy Change	DEU	Germany	1.35%	0.91%	1.66%
Bioeconomy Change	FIN	Finland	1.41%	0.91%	1.65%
Bioeconomy Change	IDN	Indonesia	5.56%	0.31%	0.57%
Bioeconomy Change	IND	India	5.35%	0.28%	1.65%
Bioeconomy Change	RUS	Russian Federation	3.13%	0.66%	0.17%
Bioeconomy Change	SWE	Sweden	1.42%	0.73%	1.36%
Bioeconomy Change	USA	United States of America	1.44%	0.76%	1.10%
Bioeconomy Islands	BRA	Brazil	2.25%	0.15%	0.22%
Bioeconomy Islands	CAN	Canada	1.33%	0.25%	0.32%
Bioeconomy Islands	CHN	China	4.18%	0.14%	1.88%
Bioeconomy Islands	DEU	Germany	1.48%	0.23%	1.64%
Bioeconomy Islands	FIN	Finland	1.60%	0.26%	1.60%
Bioeconomy Islands	IDN	Indonesia	4.45%	0.10%	0.57%
Bioeconomy Islands	IND	India	3.95%	0.13%	1.70%
Bioeconomy Islands	RUS	Russian Federation	2.86%	0.25%	0.20%
Bioeconomy Islands	SWE	Sweden	1.59%	0.24%	1.35%
Bioeconomy Islands	USA	United States of America	1.53%	0.25%	1.11%
Bioeconomy on the Drip	BRA	Brazil	2.18%	0.13%	0.22%
Bioeconomy on the Drip	CAN	Canada	1.11%	0.14%	0.32%
Bioeconomy on the Drip	CHN	China	4.01%	0.14%	1.88%
Bioeconomy on the Drip	DEU	Germany	1.22%	0.14%	1.64%
Bioeconomy on the Drip	FIN	Finland	1.30%	0.14%	1.60%
Bioeconomy on the Drip	IDN	Indonesia	4.31%	0.12%	0.54%
Bioeconomy on the Drip	IND	India	4.14%	0.13%	1.69%
Bioeconomy on the Drip	RUS	Russian Federation	2.54%	0.13%	0.20%
Bioeconomy on the Drip	SWE	Sweden	1.32%	0.13%	1.35%
Bioeconomy on the Drip	USA	United States of America	1.13%	0.14%	1.11%

Note: Note: 1 mean growth rate per year between 2015 and 2050 as calculated by SSP [28,29]; 2 growth rate of technological efficiency per year as country specific mean over all prod-ucts; Technological change is calculated separately for each product in a country via the GFPM to catch up with the BEPASO storylines; 3 Mean growth of forest stock per year from 2015 to 2050 [27].

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5. The structural gravity model and its implications on global forest product trade

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5.1. Abstract

The gravity model of trade is one of the most common approaches in modern econometrics. In its basic form the model assumes that income and distance between two partners most likely play a major role in the occurrence of trade. Despite the long history of the gravity model and its high, universal explanatory potential, its application for the forest sector is not broad and refers only to the traditional definition of the gravity approach. However, this traditional approach is not able to explain all aspects of trade at a disaggregated sector level. Consequently, the present study aims to close this research gap and reveal influencing factors for the appearance and the intensity of forest product trade by applying the structural gravity approach. This is done via linear and non-linear estimation methods for the forest sector on the whole and for thirteen forest products in details. Three major results were found: first, the traditional gravity approach overestimates the impact of the overall income on forest sector trade. Second, the appearance of wood market trade is not always influenced by the same factors as the quantity traded. And third, with increasing processing level determinants of forest product trade seems to be influenced by different factors.

Keywords: Gravity model, wood markets, forest products, bilateral trade, PPML estimator

5.2. Introduction

In the complex network of international relationships, trade plays an important role for economic development, wealth and intercultural exchange. This is why the role of trade in the forestry and wood-based sector has already been analyzed in many ways, e.g., in context of the forest transition [1], illegal logging [2] or the network theory [3]. However, trade is no exogenous factor in the forestry sector; it is influenced by factors like income, free trade agreements [4], shifting demand patterns [5] or domestic production [6]. A theory which fits all possible factors is not within reach but in 1962, Tinbergen introduced the gravity model of trade to explain international trade on the macro level [7].

The idea of trade gravity is borrowed from a basic principle of physics, where the mass of an object causes a force of attraction which diminishes with increasing distance; this force is called gravity. A similar effect can be observed in economics: the economic mass of both the domestic and the partner country attract trade while this effect is restrained by the distance between the potential trading partners. Since its first introduction, the gravity model is characterized by both a long history of applications across disciplines and by high empirical relevance [8]. However, while it gained attention in general economics, only few studies used the gravity model to describe bilateral trade in forestry and forest-based sectors. Some recent studies used this theory to explain trade flows with local focus for e.g. agricultural exports of the USA [9]; forest product trade relations between the EU member countries and Turkey [10]; forest product trade between European countries [4] or trade in Chinese bamboo and rattan products [11]. To our knowledge only two studies used the model to analyze international wood market trade in the last twenty years [12,13]. While Buongiorno [12] used only the GDP of the trading partner to describe trade flows and estimated it with linear panel methods, Larson et al. [13] additionally used the distance between partners and applied the Poisson pseudo maximum likelihood estimator (PPML), which is widely used in common gravity literature [14]. Although Larson et al. [13] mentioned that other indicators for wood market trade may exist, they did not include further variables in their study. However, these existing studies for gravity in wood markets generally used (i) the GDP as proxy for economic mass, which is usually positively related, and (ii) the distance, which is usually negatively related to trade and therefore refer to the traditional definition of the gravity model as described by Tinbergen, in 1962 [7], or Anderson, in 1979 [15]. Nevertheless, this traditional definition of gravity does only account for aggregated and not for sectoral or product specific trade. For analysis in the forest sector this might be a problem because trade pattern differ across products, e.g., the magnitude of sawnwood trade depends highly on developments in the housing sector, particle board trade has a regional focus due to its weight and newsprint trade drastically decline with increasing digitalization. The GDP as aggregated income may be a good proxy in aggregated trade analysis but if included in analysis for the forest sector it may contain aggregation bias [16,17], if sector specific effects were ignored. Existing literature does not account for this effect and leave a gap in the analysis of forest sector specific trade which the traditional gravity definition cannot close. However, the structural definition of gravity was developed to close such gaps by moving away from the intuitive traditional definition and explaining trade as a part in the total expenditures of an economy. Thus, it became able to explain trade on sector or product level and additionally could give a broad economic background [16-18].

Consequently, the present study aims to analyze forest sector specific trade by applying the structural definition of gravity. The study aims to reveal the drivers which influence the likelihood of the occurrence and the magnitude of wood market trade by applying the structural gravity approach for the forest sector. For this aim, we first explain the structural gravity theory and outline how we apply this concept in an econometric design. In the following, we explain the database on which the estimation procedure is founded. Thereafter the results are presented and discussed before we complete this study with a conclusion.

5.3. Materials and Methods

5.3.1. Methodology

The gravity model of trade may be derived as an analogy from physics, but developed further since its first introduction and became common knowledge in economics [19]. Approximately, in the last ten years it became common to estimate gravity for forest sector specific trade [4,9-13]. However, existing literature for gravity in wood markets refer only to the traditional definition of the gravity model. According to this traditional definition the specific trade flow (X) from the exporter j to importer n is influenced by the overall domestic income (Y) and bilateral accessibility (Φ) between partners. Bilateral accessibility describes time-invariant characteristics of a country pair such as distance or sharing the same language.

$$\boldsymbol{X_{nj} = {Y_j}^a * {Y_n}^b * \varphi_{nj}}$$

The multiplicative form of equation 1 results from the physical analogy and is comfortable to be estimated in log-log form with bilateral country fixed effects. Even though, this model was successful in the explanation of aggregated trade, for analysis of sector or product specific trade this traditional outline is to general [16-18]. Sector or product specific effects cannot be matched solely by the aggregated domestic income. Therefore, the gravity model was developed further into its structural definition. This definition also aims to identify drivers of the specific trade flow ($\boldsymbol{X_{nj}}$). Apart from material flow trade can also be described by the flow of money. This expenditure from n to j for a specific product can be seen as a share ($\boldsymbol{\pi_{nj}}$) of the total expenditures in country n ($\boldsymbol{X_n}$).

$$\boldsymbol{X_{nj} = \pi_{nj} X_n}$$

Now, the main issue in the context of structural gravity is to explain the share of total domestic expenditures to a specific trade flow. Through steps of transformation (see appendix or [18]), equation 2 leads to equation 3. Here, the import in country n is explained by the total production in country j ($\boldsymbol{Y_j}$), an index of market potential in j ($\boldsymbol{\Omega_j}$), the degree of competition in that market ($\boldsymbol{\Phi_n}$) and bilateral accessibility ($\boldsymbol{\varphi_{nj}}$). While the index of market potential covers the maximal possible sales from j in the world (and in domestic market), the degree of competition captures the sum of all export capabilities (and domestic production) to n.

$$\boldsymbol{X_{nj} = \frac{Y_j}{\Omega_j} \frac{X_n}{\Phi_n} \varphi_{nj}}$$

Equation 3 covers this structural definition of gravity and explains why income plays such an important role for bilateral trade in aggregated markets:

"At the aggregate level one should measure $\boldsymbol{Y_j}$ as gross production (not value-added) of traded goods (assuming $\boldsymbol{X_{nj}}$is merchandise trade) and $\boldsymbol{X_n}$should be apparent consumption of goods (production plus imports minus exports). However, in practice GDP is often used as a proxy for both $\boldsymbol{Y_j}$ and $\boldsymbol{X_n}$" [18] (p. 138).

For sectoral specific application of the structural gravity, Y_j can be interpreted as the sectoral production in the exporting country and X_n as the sectoral consumption in the importing country. Again, bilateral accessibility ($\boldsymbol{\varphi_{nj}}$) describes time-invariant characteristics of a country pair such as distance or sharing the same language. However, as $\boldsymbol{\Omega_j}$ and $\boldsymbol{\Phi_n}$ cover potential market developments, they are difficult to measure for an econometric ex post analysis. In order to reach an approximation for market potential ($\boldsymbol{\Omega_j}$) we assume that the sectoral consumption in the exporting country equals the maximum possible sales from j in the world (and in domestic markets) because consumption (defined as production – export + import) captures the domestic need of a product and therefore the potential to export to other countries. Further, for the degree of competition ($\boldsymbol{\Phi_n}$) it is assumed that the capability to export to a certain country is dependent on the existing production in the importing country. Therefore, the degree of competition in this study will be established by the production in the importing country.

In the next step we transfer this theoretical framework of gravity into econometric analysis by applying a simple OLS regression with importer and exporter fixed effects [20]. This fixed-effects approach (FE) is chosen because bilateral trade data contain individual effects for importer as well as for exporter countries. A simple OLS, therefore, would be biased a priori by this individual heterogeneity. Since the gravity model is nonlinear and the FE is designed for linear problems Equation 2 has to be transformed in log-log form:

$$X_{nj} = Exp\left(ln\,\alpha + ln\,\beta_1 Y_j + ln\,\beta_2 X_n + ln\,\beta_3 \varphi_{nj} + ln\,\beta_4 \Omega_j + ln\,\beta_5 \Phi_n\right)$$

However, this log-log form can cause another problem: if heteroscedasticity is still persistent within the FE framework the estimation would be biased, because of Jensen´s inequality E(ln Y) ≠ ln E(Y). For this reason a Poisson pseudo maximum likelihood estimator (PPML) with importer and exporter dummies is suggested to estimate gravity models [21]. The PPML estimation has the advantage that it can be estimated in nonlinear form and, in addition, still works if zeros entries (the non-existence of trade between single countries) are included in trade data. Especially the latter issue is problematic in the log-log form of FE:

"Since it is not possible to raise a number to any power and end up with zero, the log of zero is undefined, and zero-trade flows cannot be treated with logarithmic specifications. At the same time, they need to be dealt with since they are non-randomly distributed. They indicate absence of trade, hence suggesting that barriers to trade are prohibitive to allowing a particular trade relationship to take place at a given demand and supply" [8] (p. 82).

Additionally, it may be possible that the likelihood of the occurrence and the magnitude of trade have different backgrounds. This study separates both problems and tests whether PPML with zero trade flows and PPML without zero trade flows differ significantly. A significant difference in the results of these two approaches could hint at the possibility that the appearance of wood market trade and its intensity may be influenced by different factors. To test for the equality - or differences - of modelling results obtained with the two PPML approaches, we follow the approach of [22] with the null hypothesis (H^0) that the coefficients estimated with the two PPML models do not significantly differ. In case testing procedure shows that the coefficients for the PPML estimations significantly differ, we apply a Maximum-Likelihood approach (ML) with importer and exporter dummies. This procedure is done because Larson et al. [13] found that it may be possible that a PPML with and without zero trade in the forest sector differ. However, such difference may be important in sector specific trade flows and could therefore be a crucial part in the estimation of gravity in forest sector. For this purpose, we apply ML estimation with the binary response variable, trade (1) or no trade (0). With this method it is possible to interpret factors which influence only the likelihood that trade happens.

Summarizing our approach, we start with the estimation of FE, then we test on the existence of heteroscedasticity and if it was found we apply the PPML estimations. The PPML will be applied for data with and without zeros in trade flows and the results of both estimations will be compared with each other by applying the approach of [22] and - in case they differ - we use a ML model to explain the reason of the difference. All estimations in this whole approach control for time-varying effects by including time fixed effects.

5.3.2. Data

Regarding structural gravity theory, five main influencing variables can be listed in the context of bilateral trade in wood markets: the production value of the exporter, the value of expenditures in the importing country, the production capacity of the exporter, market competition in the importing country and the accessibility from exporting to importing markets. However, because these variables have almost no direct equivalent observation in global databases, the present study has to use proxies which fit in these categories. Therefore, we collect data from different sources to capture as many determinants of wood market trade as possible. The database of the Centre d'études prospectives et d'informations internationals (CEPII) identifies proxies for market accessibility [23,24]. The forestry databases of the Food and Agriculture Organization of the United Nations (FAO) are used to explain trade and production data for fourteen major wood products (an overall 'forest products' category, industrial roundwood, sawnwood, veneer sheets, plywood, fiberboard, wood pulp, newsprint, paper & paperboard, industrial roundwood coniferous, industrial roundwood tropical, industrial roundwood non-coniferous, sawnwood coniferous and sawnwood non-coniferous) [25,26]. And the World Development Indicators (WDI) provides data for income [27]. Altogether the database we gathered contains 74 variables (see Table 5.4 in Appendix). However, choosing the most fitting variables for consistent analysis over fourteen product groups is complex. We decided to group all variables in one of the five categories of the structural gravity approach (total expenditures, total production, market potential, degree of competition and bilateral accessibility) and applied FE estimations with various combinations of these five categories. We compared the results via adjusted R^2, the AIC and BIC and found that some variables are more likely to be part of a good specified product specific model than other. These variables were displayed in Table 5.1. Even though, these variables were not part in any of the most fitting product specific models they were always important factors. Therefore, in the following we will show only results for the variables displayed in Table 5.1. As response variable, we choose the export over the import value because this is not biased by tariffs or other trade costs.

In the following we will introduce the determinants of global wood market trade flows defined for the present study. First, total production in the exporting country should be positively related to trade. For this category we suggest three possible variables: GDP per capita, forests rents and the quantity of production in the exporting country. Here, the econometric approach for the forest sector differs from general structural gravity approaches. Albeit in a macro perspective, gross domestic production equals GDP, in a sectoral perspective it does not. Here the sectoral production is important. This sectoral production can be observed, e.g., by forest rents[5] or the specific production of a product. However, GDP per capita should not be ignored in this category because it could also be a proxy for, e.g., the sectoral production potential.

Table 5.1 Determinants of global wood market trade

Name	Category	Unit	Source
Export Value	X_{nj}	current US$	[26]
GDP per capita (exporter)	Y_j	current US$	[27]
GDP per capita (importer)	X_n	current US$	[27]
Forest Rents (exporter)	Y_j	% of GDP	[27]
Forest Rents (importer)	X_n	% of GDP	[27]
Production (exporter)	Y_j	1 000 m^3	[25]
Consumption (importer)	X_n	1 000 m^3	[25]
Production (importer)	Φ_n	1 000 m^3	[25]
Consumption (exporter)	Ω_j	1 000 m^3	[25]
Distance between Capitals	ϕ_{nj}	km	[23,24]
Continuous Countries	ϕ_{nj}	binary	[23,24]
Same Official Language	ϕ_{nj}	binary	[23,24]
Free Trade Agreement	ϕ_{nj}	binary	[23,24]
one partner is EU member	ϕ_{nj}	binary	[23,24]
both partners are EU member	ϕ_{nj}	binary	[23,24]

In the following we will introduce the determinants of global wood market trade flows defined for the present study. First, total production in the exporting country should be positively related to trade. For this category we suggest three possible variables: GDP per capita, forests rents and the quantity of production in the exporting country. Here, the econometric approach for the forest sector differs from general structural gravity approaches. Albeit in a macro perspective, gross domestic production equals GDP, in a sectoral perspective it does not. Here the sectoral production is important. This sectoral production can be observed, e.g., by forest rents[6] or the specific production of a product. However, GDP per capita should not be ignored in this category because it could also be a proxy for, e.g., the sectoral production potential.

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[5] Forest rents in percentage of GDP (the variable is taken from the WDI. The World Bank estimated it by using roundwood harvest times, the product of average prices and a region-specific rental rate [27])

[6] Forest rents in percentage of GDP (the variable is taken from the WDI. The World Bank estimated it by using roundwood harvest times, the product of average prices and a region-specific rental rate [27])

Second, total expenditures in the importing country can be determined by its GDP per capita, the related forests rents and the consumption of certain products. All variables in this category should also be positively related to trade.

Third, for the category ‘market potential’ we define the consumption of a certain product in the exporting country as a proxy variable. Here, the consumption can be interpreted as the total demand of the product which would compete with supply for exports. If the domestic demand for a product is high this should reduce exports. The overall production of a good in the importing country in this study will be used as proxy to cover the degree of competition in the importing country. This is done because the export to one country will always compete with the domestic production in the importing country. However, both the degree of competition in the exporting country and the market potential in the importing country are difficult to measure but should be negatively related to trade.

Fourth, market accessibility can by determined by distance, cultural similarities or trade politics between two countries. Distance can be measured between capitals, economic centers or some other geographic points. In this study we decide to use the distance between capitals as a measure for distance. However, this measure does not inform about direct borders. For example the distance between Peking (China) and Moscow (Russia) is 5795 km while the distance between Moscow and Berlin (Germany) is 1614 km [23], even though Germany and Russia do not share a border. It could be assumed that closer the distance, the greater the chance that trade could occur between the partner countries. Nevertheless, Russian exports to China count for 12.4% of its total export value of wood products while exports to Germany count only for 7.6% [28]. This effect, to some degree, can be explained by the difference in total GDP between Germany and China, but the direct border shared by Russia and China may also play a role. While trade between Germany and Russia has to cross a minimum of two borders (except for transports by sea or by plane), trade between Russia and China can take place directly at the shared border. Therefore, a parameter covering continuous countries should be included in the econometric specification of the gravity theory in addition to the mere distance. Cultural similarities and trade politics, like sharing the same language, being members of the EU or other free trade agreements, could ease negotiations or bureaucracy which, in turn, could also raise trade activities between countries. Thus, the present study includes dummy variables for contiguous countries, countries sharing the same language, being members of the EU, the existence of free trade agreements and the distance between the capital cities of two countries to explain the category market accessibility.

5.4. Results and Discussion

In the following we will present the results of the structural gravity approach created in the present work. Therefore, we start with the product group 'forest products', which is the aggregate of all forest products. It is notably that for 'forest products' trade is positive dependent on the income of both partners while it is negative dependent on the distance between these partners (see Table 5. 2). The traditional definition seems to hold even in the structural gravity environment. This result is independent from the underlying estimation method: FE, PPML with zero trade flows, and PPML without zero trade flows and ML yield to the same finding. Notwithstanding, to test for the best estimation model a Breusch-Pagan-test was conducted. This points to heteroscedasticity in the FE model and implicates that the PPML model should be preferred over the FE linear regression model. Following the approach of [22] we also find significant differences between PPML estimation with and without zero entries in the export value. However, the differences between the PPML models are small and the estimated coefficients behave similar in both models. The ML estimation then gives information about the reasons of the small differences between the PPML models: contrary to the magnitude of trade, the likelihood of the occurrence of trade is not influenced by forest rents of the exporting country. In contrast, the language in both partner countries is an important factor for the likelihood of the occurrence of trade, but not for the magnitude of trade. Finally, while the magnitude of trade is negatively dependent on the consumption in the exporting country, the likelihood of the occurrence of trade is positively dependent on it.

As mentioned above, forests rents, consumption, and the GDP of importing countries can be interpreted as proxies for total import expenditures. Within the framework of structural gravity, this interpretation leads to the assumption that all three variables are positively correlated with trade. However, our results reveal that only the consumption of forest products and the GDP in importing countries show significant positive signs in estimations. In contrast, forest rents in importing countries are negatively significant. Together with the non-significant influence of production in importing countries, this leads to the conclusion that, contrary to theoretical classification above, forest rents in importing countries function like the degree of competition in the importing country. On the other hand and within the framework of structural gravity, production, forest rents and the GDP in the exporting country can be interpreted as part of the production value of the exporter. These variables behave exactly as suggested above and thus, influence trade in a positive way, based on our results. Further, according to our results it seems that the consumption in exporting countries is a suitable proxy for the market potential of the exporter as it significantly influences the magnitude of trade in a negative way.

Table 5. 2 Estimation results for the product group 'forest products'

	ML			PPML^1			PPML^2			FE		
Constant	-6.104	(-0.32)	***	0.013	(-3.03)		-1.668	(-2.9)				
Forest Rents (exporter)	-0.018	(-0.01)		0.211	(-0.02)	***	0.193	(-0.02)	***	0.137	(-0.01)	***
Forest Rents (impor-	-0.053	(-0.01)	***	-0.085	(-0.03)	*	-0.117	(-0.03)	***	-0.044	(-0.01)	***
Production (exporter)	0.057	(-0.01)	***	0.835	(-0.06)	***	0.833	(-0.05)	***	0.128	(-0.01)	***
Production (importer)	0.013	(-0.01)		-0.015	(-0.01)		-0.008	(-0.01)		-0.01	(-0.01)	
Consumption (expor-	0.284	(-0.02)	***	-0.335	(-0.05)	***	-0.321	(-0.04)	***	0.229	(-0.02)	***
Consumption (impor-	0.403	(-0.02)	***	0.516	(-0.03)	***	0.52	(-0.03)	***	0.413	(-0.02)	***
GDP per capita (expor-	0.212	(-0.02)	***	0.254	(-0.02)	***	0.27	(-0.02)	***	0.418	(-0.02)	***
GDP per capita (impor-	0.257	(-0.02)	***	0.169	(-0.02)	***	0.181	(-0.02)	***	0.23	(-0.01)	***
Distance between Ca-	-1.177	(-0.01)	***	-0.747	(-0.01)	***	-0.758	(-0.01)	***	-1.429	(-0.01)	***
Continuous Countries	0.223	(-0.06)	***	0.742	(-0.02)	***	0.732	(-0.02)	***	0.595	(-0.04)	***
Same Official Language	0.64	(-0.03)	***	-0.038	(-0.02)		-0.031	(-0.02)		0.517	(-0.02)	***
Free Trade Agreement	0.225	(-0.03)	***	0.494	(-0.02)	***	0.518	(-0.02)	***	0.399	(-0.02)	***
one partner is EU	-0.197	(-0.04)	***	-0.227	(-0.04)	***	-0.206	(-0.04)	***	0.006	(-0.03)	
both partners are EU	0.719	(-0.12)	***	0.21	(-0.08)	**	0.209	(-0.08)	**	0.347	(-0.06)	***
N	148639			78893			148639			78893		
Pseudo R²/ adj. R²	0.449			0.886			0.886			0.647		

Note: PPML^1 = PPML without zero-trade; PPML^2 = PPML with zero-trade; Standard errors in parentheses; ***, **, and * are significant at the 0.1%, 1%, and 5% level, respectively.

In reference to the bilateral market accessibility we find evidence that it is determined by the distance, a common border and the existence of free trade agreements between trading partners. Results show that with increasing distance both, the magnitude and the likelihood of the occurrence of trade, are significantly negatively influenced, while sharing a border increases both components of trade. In general, we find that free trade agreements have a significant positive effect on trade, too. The membership in the EU turns out to be a special case in the context of free trade agreements. We find that it is an advantage for trade activities only if both partners are member of the EU but a disadvantage if only one partner is an EU member. Sharing the same language only increases the likelihood of the occurrence of trade but not its magnitude and can therefore only partly be interpreted as a variable in our structural gravity model which eases market accessibility.

In the next step, more detailed results will be presented for all 13 individual products. For this purpose we group the individual products into the groups ’industrial roundwood’, ’sawnwood’, ’veneer, plywood and fiberboard’ and ‘wood pulp, newsprint and paper & paperboards’. For all individual products we conduct Breusch-Pagan Tests and subsequently the approach of Paternoster [22], but we always find that the FE contains heteroscedasticity and both PPML approaches differ significantly. Therefore, the following results will be presented only for the estimation methods ML and PPML without zero trade flows.

5.4.1. Industrial Roundwood

In contrast to other product groups, industrial roundwood trade is significantly less driven by economic dependencies (see Table 5.5 in appendix). Factors like domestic production or consumption do not influence the trade of any of the four products of industrial roundwood (tropical, coniferous, non-coniferous, as well as the aggregate of all three products). For the aggregated industrial roundwood and coniferous industrial roundwood, the GDP of the exporting country influence the magnitude of trade significant negatively. For non-coniferous industrial roundwood exporters GDP has no significant impact on the magnitude of trade but the occurrence of trade is significant less likely if the GDP of the exporter is high. Consequently, our results suggest that high income countries attract industrial roundwood from low income countries. The opposite effect can be observed for the tropical parts of industrial roundwood. Here the magnitude of trade is significant positive dependent on the income of the exporter and significant negative dependent of the importer’s income. Another interesting result is that free trade agreements influence the magnitude of trade for non-coniferous and tropical industrial roundwood significant negatively. An explanation for such relationship may be that free trade agreements go along with harmonized regulations and decreasing levels of protectionism. Altogether, the structural gravity approach does not seem to be the best approach to explain trade in the industrial roundwood product group. Within this group trade may be influenced by interrelations which were not subject of the present study. However, it is possible that these results can, to some degree, be explained by the raw material character of industrial roundwood.

5.4.2. Sawnwood

For the aggregated sawnwood product (coniferous plus non-coniferous) the GDP in the importing country is significant positive related to the magnitude of trade (see Table 5.6 in appendix). The GDP in the exporting country have no significant influence on the magnitude of trade. Contrarily, the likelihood of the occurrence of trade is dependent of GDP in both importing and exporting partner countries, based on the ML results. In contrast to industrial roundwood, here all coefficients, except of sharing the same language and forest rents in the importing country, behave as the theory suggests. Interestingly, the likelihood of trade for the aggregated sawnwood is not significant influenced by the distance between partners. This interrelation is unique for all estimations in this study. However, the trade for both individual products, coniferous and non-coniferous sawnwood, behaves mostly as structural gravity theory suggested. But it is contrary to the expectation that the income of exporting countries shows a significant negative influence on the magnitude of trade for non-coniferous sawnwood. As for non-coniferous industrial roundwood an explanation for this effect might be that high income countries attract non-coniferous sawnwood from low income countries

5.4.3. Veneer, Plywood and Fibreboard

Contrary to the trade of sawnwood, we find that the importers' GDPs do not influence the trade value of wood panels positively (see Table 5.7 in appendix). For plywood and fibreboard there is no significant influence and for veneer this interrelation is negative significant. However, most coefficients influence the magnitude of trade and the likelihood of its occurrence for the individual products of this product group in the way the structural gravity approach above suggested. Even though, the EU membership of only one partner is significant negatively related to the magnitude and also to the likelihood of the occurrence of fibreboard trade. However, the EU membership of both trade partners does not influence any kind of fibreboard trade.

5.4.4. Wood pulp, Newsprint and Paper & Paperboards

For the product 'paper & paperboards', the income in the importing country is significant negatively related to the magnitude of trade while the income of the exporting country is significant positively related to the magnitude of trade (see Table 5. 8 in appendix). This implies that it is likely that countries with higher income export paper & paperboards to countries with lower income. The level of consumption, on the other hand, is significant positively related to the magnitude of trade in both the importing and the exporting country, which implies that the demand for paper & paperboards in the exporting country does not restrict export quantities. For the product newsprint the magnitude of trade is not significant influenced by the GDP of one trade partner. However, the occurrence of trade for this product significantly increases if the GDP in the exporting country is increasing. Eventually, instead of GDP, the domestic production seems to be the "economic mass" variable for newsprint trade. Here the traditional gravity approach has fallen short in the past, since it aims to specify the driving variable but failed because it did only investigate GDP and distance as possible determinants. On the other hand, the traditional gravity approach holds for wood pulp trade, but can be expanded by production and forest rents of the exporting country as well as the consumption of the importing country (all three are significant positive related to the magnitude of trade).

After the presentation of results in general and detailed for 13 individual products we compare the results for individual wood products with each other (results in Table 5.5 to Table 5. 8, see appendix). In this regard, one of our main findings is that with increasing complexity in the manufacturing process trade is determined by varying factors. For industrial roundwood, e.g., we find that processing is noticeably less influenced by factors like rents in the forest sector or free trade agreements compared to paper products. It also holds that, if one of the trade partners is an EU member, this is an advantage for trade with industrial roundwood, sawnwood and veneer but it is a disadvantage for trade with paper products. However, if both partners are EU members, forest products trade is always increasing (except for wood pulp and newsprint as in this case this variable does not influence trade).

In the last part of this chapter we will compare the results, obtained in this study, with previous studies. For that, we only use results estimated with similar methods and product categories. We found that in the structural gravity environment, the GDP effect seems to be smaller as noted in previous studies (see Table 5.3). This conclusion holds for all GDP coefficients with the exception of paper products where the GDP effect for the exporter is higher than the result suggested in [12,13]. Thus, we conclude that the traditional gravity approaches applied in the past may overestimate the impact of GDP on forest sector trade by not accounting for forest sector specific effects.

Table 5.3 Comparison of GDP effects from structural (own estimations) and traditional gravity (results from [12,13])

Product	Variable	Traditional Gravity FE [12]		Structural gravity FE		Traditional Gravity PPML [13]		Structural gravity PPML	
Wood	exporter GDP	0.44		-0.021					
	importer GDP	1.9	***	0.297	***				
Wood pulp	exporter GDP	1.63	**	0.23	***	0.685	***	0.344	***
	importer GDP	1.24	**	0.22	***	1.022	***	0.499	***
Paper	exporter GDP	0.24		0.72	***	0.396	***	0.411	***
	importer GDP	1.04	***	0.08	***	0.767	***	-0.074	***
Sawnwood non–conif.	exporter GDP					0.798	***	0.289	***
	importer GDP					0.846	***	0.384	***

Note: PPML = PPML with zero-trade; ***, **, and * are significant at the 1%, 5%, and 10% level, respectively.

5.5. Conclusion

In the present study, we apply a structural gravity model to explain the occurrence and magnitude of trade between two countries. This approach goes beyond the framework of previous studies, which concentrate on the application of a more traditional approach of gravity. Summarizing, we found that this structural gravity approach offers a more detailed look about the factors which influence bilateral trade in this sector as the traditional gravity model could do. Simultaneously it also provides a broader theoretical background. Nevertheless, the GDP as an aggregated factor is still a powerful tool to explain trade in the forest sector. The question why such aggregated factor influences forest sector specific trade cannot finally be clarified by this study and remains for further research. However, the present study showed that past studies, which used the traditional gravity definition, overestimates the aggregated GDP effect on forest sector trade. The structural gravity framework, on the other hand, tries to explain parts of this general GDP effect by including forest-sector specific parameters like domestic production, consumption or forest rents in the econometric analysis. Further research could aim to identify determinants of product specific trade which potentially explain the influence of aggregated parameters, like GDP, even in more details.

Another finding of this study is that trade for further processed wood products behave differently than trade for raw materials, e.g., while trade for industrial roundwood increases with lower incomes in the exporting, and higher incomes in the importing country, the reverse relationship can be found in paper & paperboards. This effect may be observed because wood processing industry can be located in countries with higher income, while low income countries more likely export the raw materials.

Finally, this study aims to identify factors influencing both the likelihood and the magnitude of trade flows. We find that in most cases these determinants behave similarly for both trade characteristics. However, for some product groups there is a significant difference between these characteristics. The consumption of the overall forest product category, for example, is positively related to the occurrence and negatively related to the magnitude of trade. Even more interesting is the fact that the occurrence of aggregated sawnwood trade is not determined by the distance between trade partners, while the magnitude of trade is negatively dependent on this distance. This effect does only hold for this aggregated sawnwood and not for coniferous respectively non-coniferous sawnwood and may result from the issue that aggregated product trade response differently than disaggregated product trade to external characteristics. This should be kept in mind for further research.

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5.6. Appendix

This definition of structural gravity can be explained by the specific trade flow (X_{nj}) which is described as expenditure from n to j for a specific product. However, this expenditure is only a share (π_{nj}) of the total expenditures in country n (X_n).

$$\boldsymbol{X_{nj} = \pi_{nj} X_n}$$

The derivation of structural gravity starts by describing the share of total domestic expenditures to a specific trade flow:

$$\boldsymbol{\pi_{nj} = \frac{S_j \varphi_{nj}}{\Phi_n}}$$

Here S_j capture the capability of j to export, φ_{nj} the bilateral accessibility and Φ_n the set of opportunities for consumers in n and therefore the sum of all export capabilities to n $\Phi_n = \sum_l S_l \varphi_{nl}$. Inserting equation 6 in 5 leads to:

$$\boldsymbol{X_{nj} = \frac{S_j \varphi_{nj}}{\Phi_n} X_n}$$

The sum of all exports and the domestic production (X_{nn}) is defined as Y_j:

$$\boldsymbol{Y_j = \sum_l X_{lj}}$$

Applying this accumulation for equation 7 leads to:

$$\boldsymbol{Y_j = S_j \sum_l \frac{\varphi_{lj} X_l}{\Phi_l}}$$

Introducing Ω$_j$ as an index for market potential which cover the maximal possible sales from j throughout the world $\Omega_j = \sum_l \frac{\varphi_{lj} X_{lj}}{\Phi_l}$ and inserting it into equation 9 leads to:

$$\boldsymbol{S_j = \frac{Y_j}{\Omega_j}}$$

Inserting equation 10 in 7 leads to:

$$\boldsymbol{X_{nj} = \frac{Y_j}{\Omega_j} \frac{X_n}{\Phi_n} \varphi_{nj}}$$

Equation 11 is then the resulting structural gravity estimation as described by [18]

Table 5.4 Total variable selection

ID	Variable	Variable exist for both partner countries	Source
1	Export Value		[26]
3	Consumption	Yes	[25]
5	Production	Yes	[25]
7	Consumption of all forest products	Yes	[25]
9	Export quantity of all forest products	Yes	[25]
11	Import quantity of all forest products	Yes	[25]
13	Production quantity of all forest products	Yes	[25]
15	Deflated Agricultural Sector	Yes	[27]
17	Forest Rents	Yes	[27]
19	Forest Area	Yes	[27]
21	Population	Yes	[27]
23	Population density	Yes	[27]
25	Area in sq. km	Yes	[23,24]
26	Colony from		[23,24]
27	Colony to		[23,24]
28	Colony		[23,24]
29	Colony before 1945		[23,24]
30	Common Currency		[23,24]
31	Common Religion		[23,24]
32	Continuous Countries		[23,24]
34	Cost start-up procedures (% of GNI per cap.)	Yes	[23,24]
35	Current Colony		[23,24]
36	Current Sibling		[23,24]
38	Days + Procs to start a business	Yes	[23,24]
39	Distance		[23,24]
40	Distance between Capitals		[23,24]
41	Distance Weighted		[23,24]
42	Distance Weighted (distwces)		[23,24]
44	donator of GSP	Yes	[23,24]
45	Empire		[23,24]
47	EU member	Yes	[23,24]
48	Free Trade Agreement (WTO)		[23,24]
50	GATT/WTO member	Yes	[23,24]
52	Hegemon	Yes	[23,24]
53	Hours diff. between partners		[23,24]
54	Independence date		[23,24]

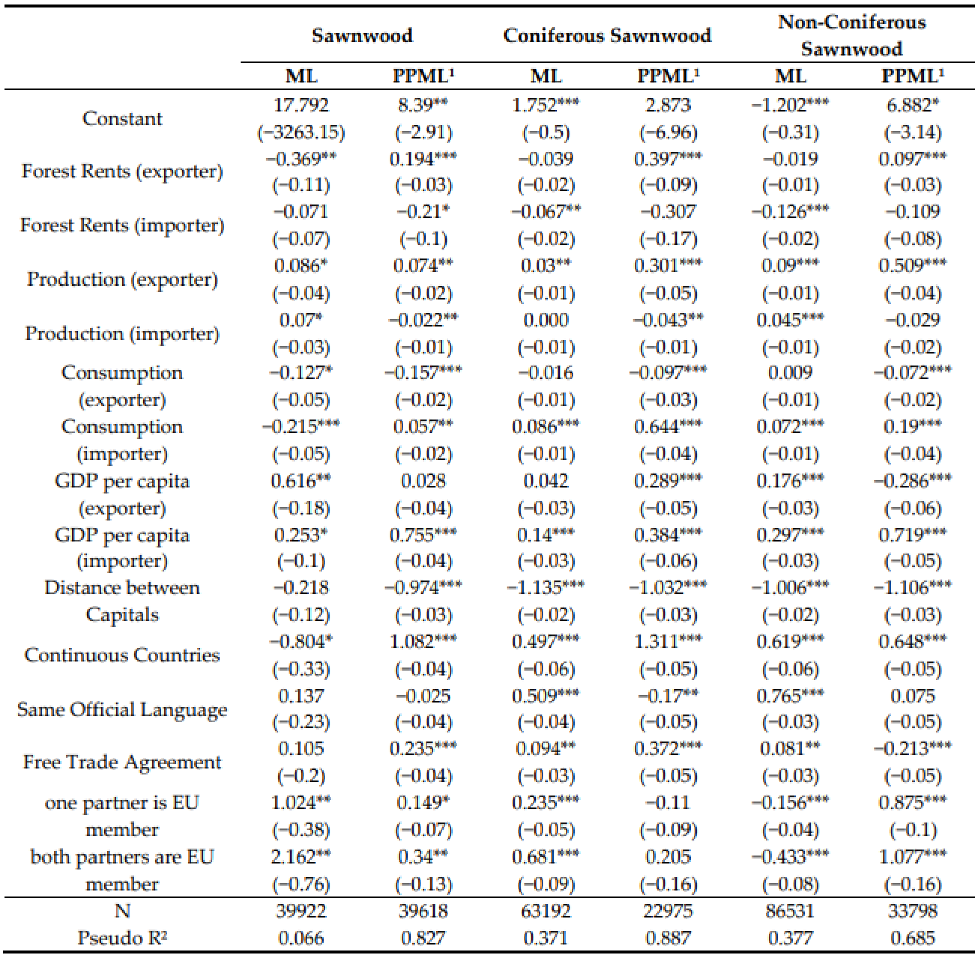
56	legal system after transition	Yes	[23,24]
58	legal system before transition	Yes	[23,24]
59	part of the same Country		[23,24]
60	preferential trade area		[23,24]
62	report of changes in Rose data	Yes	[23,24]
63	Same Ethnical Language		[23,24]
64	Same Official Language		[23,24]
65	Sever		[23,24]
66	Sibling		[23,24]
67	Sibling with Conflict		[23,24]
69	Procedures to register a business	Yes	[23,24]
71	Time to start a business(days)	Yes	[23,24]
73	trade between Africa, ACP and EU	Yes	[23,24]
74	War between partners		[23,24]

Table 5.5 Estimation results for the product group ‘industrial roundwood’

	Total Industrial Roundwood		Conif. Industrial Roundwood		Trop. Industrial Roundwood		Non-Conif. Industrial Roundwood	
	ML	**PPML^1**	**ML**	**PPML^1**	**ML**	**PPML^1**	**ML**	**PPML^1**
Constant	25.809 (−2620.8)	10.506 (−8.11)	−0.042 (−1.12)	9.054 (−46.06)	1.379 (−1.55)	19.698 (−240.71)	−0.759 (−0.52)	8.699 (−10.17)
Forest Rents (exporter)	−0.146 (−0.13)	0.171*** (−0.02)	−0.016 (−0.03)	0.324 (−0.26)	0.024 (−0.02)	0.164** (−0.06)	−0.066** (−0.02)	0.078* (−0.04)
Forest Rents (importer)	−0.026 (−0.06)	0.085 (−0.15)	−0.019 (−0.03)	0.144 (−0.46)	−0.125* (−0.05)	0.348 (−0.4)	−0.078** (−0.03)	0.204 (−0.24)
GDP per capita (exporter)	−0.299* (−0.13)	−0.279*** (−0.06)	−0.074 (−0.04)	−0.644*** (−0.13)	−0.201*** (−0.04)	0.936** (−0.32)	−0.116*** (−0.03)	0.158 (−0.09)
GDP per capita (importer)	−0.28* (−0.14)	0.856*** (−0.05)	0.535*** (−0.05)	1.341*** (−0.12)	0.46*** (−0.05)	−0.527* (−0.23)	0.381*** (−0.04)	0.646*** (−0.09)
Distance between Capitals	−0.486*** (−0.08)	−1.152*** (−0.05)	−1.145*** (−0.03)	−1.196*** (−0.12)	−0.587*** (−0.03)	−1.369*** (−0.34)	−0.907*** (−0.02)	−1.253*** (−0.07)
Continuous Countries	0.189 (−0.2)	1.677*** (−0.07)	0.638*** (−0.07)	1.797*** (−0.15)	0.695*** (−0.08)	0.627 (−0.46)	0.782*** (−0.06)	1.624*** (−0.12)
Same Official Language	−0.07 (−0.14)	−0.172* (−0.07)	0.612*** (−0.05)	0.111 (−0.22)	0.414*** (−0.06)	−0.274 (−0.26)	0.555*** (−0.04)	−0.248* (−0.1)
Free Trade Agreement	−0.187 (−0.13)	−0.025 (−0.07)	0.137** (−0.04)	0.681*** (−0.13)	−0.136* (−0.06)	−0.677* (−0.33)	0.003 (−0.04)	−0.529*** (−0.11)
one partner is EU member	0.207 (−0.21)	0.364** (−0.14)	0.039 (−0.07)	0.075 (−0.29)	0.046 (−0.11)	2.211 (−3.23)	−0.023 (−0.06)	0.419* (−0.19)
both are EU member	−0.046 (−0.36)	1.064*** (−0.21)	0.391*** (−0.11)	0.998* (−0.41)	0.559** (−0.19)	4.63 (−6.34)	−0.009 (−0.1)	0.36 (−0.29)
N	22146	21299	41461	11279	30450	6421	51955	15124
Pseudo R^2	0.132	0.727	0.357	0.765	0.228	0.584	0.308	0.655

Note: PPML^1 = PPML without zero-trade; Standard errors in parentheses; ***, **, and * are significant at the 0.1%, 1%, and 5% level, respectively.

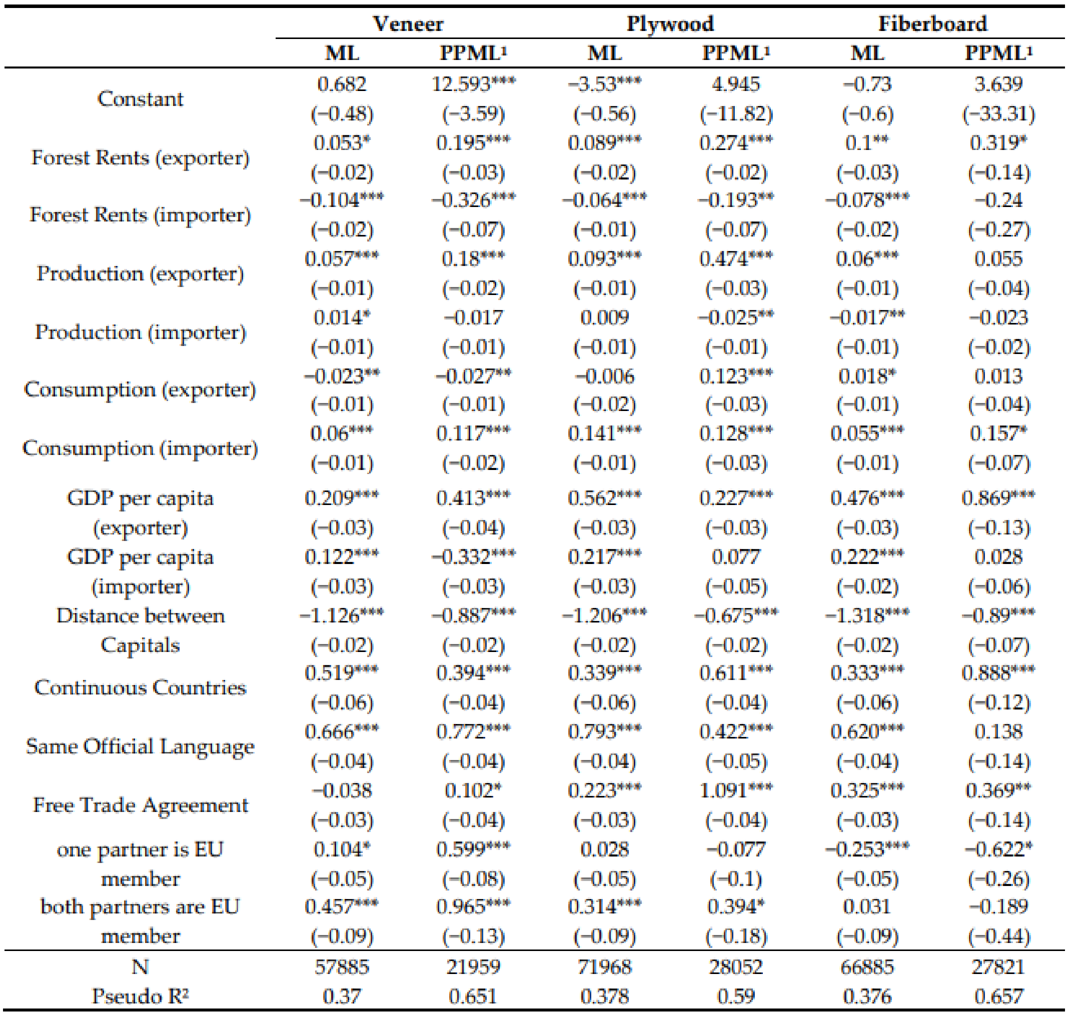
Table 5.6 Estimation results for the product group ‘sawnwood’



	Sawnwood		**Coniferous Sawnwood**		**Non-Coniferous Sawnwood**	
	ML	**PPML^1**	**ML**	**PPML^1**	**ML**	**PPML^1**
Constant	17.792	8.39**	1.752***	2.873	−1.202***	6.882*
	(−3263.15)	(−2.91)	(−0.5)	(−6.96)	(−0.31)	(−3.14)
Forest Rents (exporter)	−0.369**	0.194***	−0.039	0.397***	−0.019	0.097***
	(−0.11)	(−0.03)	(−0.02)	(−0.09)	(−0.01)	(−0.03)
Forest Rents (importer)	−0.071	−0.21*	−0.067**	−0.307	−0.126***	−0.109
	(−0.07)	(−0.1)	(−0.02)	(−0.17)	(−0.02)	(−0.08)
Production (exporter)	0.086*	0.074**	0.03**	0.301***	0.09***	0.509***
	(−0.04)	(−0.02)	(−0.01)	(−0.05)	(−0.01)	(−0.04)
Production (importer)	0.07*	−0.022**	0.000	−0.043**	0.045***	−0.029
	(−0.03)	(−0.01)	(−0.01)	(−0.01)	(−0.01)	(−0.02)
Consumption (exporter)	−0.127*	−0.157***	−0.016	−0.097***	0.009	−0.072***
	(−0.05)	(−0.02)	(−0.01)	(−0.03)	(−0.01)	(−0.02)
Consumption (importer)	−0.215***	0.057**	0.086***	0.644***	0.072***	0.19***
	(−0.05)	(−0.02)	(−0.01)	(−0.04)	(−0.01)	(−0.04)
GDP per capita (exporter)	0.616**	0.028	0.042	0.289***	0.176***	−0.286***
	(−0.18)	(−0.04)	(−0.03)	(−0.05)	(−0.03)	(−0.06)
GDP per capita (importer)	0.253*	0.755***	0.14***	0.384***	0.297***	0.719***
	(−0.1)	(−0.04)	(−0.03)	(−0.06)	(−0.03)	(−0.05)
Distance between Capitals	−0.218	−0.974***	−1.135***	−1.032***	−1.006***	−1.106***
	(−0.12)	(−0.03)	(−0.02)	(−0.03)	(−0.02)	(−0.03)
Continuous Countries	−0.804*	1.082***	0.497***	1.311***	0.619***	0.648***
	(−0.33)	(−0.04)	(−0.06)	(−0.05)	(−0.06)	(−0.05)
Same Official Language	0.137	−0.025	0.509***	−0.17**	0.765***	0.075
	(−0.23)	(−0.04)	(−0.04)	(−0.05)	(−0.03)	(−0.05)
Free Trade Agreement	0.105	0.235***	0.094**	0.372***	0.081**	−0.213***
	(−0.2)	(−0.04)	(−0.03)	(−0.05)	(−0.03)	(−0.05)
one partner is EU member	1.024**	0.149*	0.235***	−0.11	−0.156***	0.875***
	(−0.38)	(−0.07)	(−0.05)	(−0.09)	(−0.04)	(−0.1)
both partners are EU member	2.162**	0.34**	0.681***	0.205	−0.433***	1.077***
	(−0.76)	(−0.13)	(−0.09)	(−0.16)	(−0.08)	(−0.16)
N	39922	39618	63192	22975	86531	33798
Pseudo R^2	0.066	0.827	0.371	0.887	0.377	0.685

Note: PPML^1 = PPML without zero-trade; Standard errors in parentheses; ***, **, and * are significant at the 0.1%, 1%, and 5% level, respectively.

Table 5.7 Estimation results for the product group ‘veneer, plywood and fibreboard’



	Veneer		Plywood		Fiberboard	
	ML	PPML^1	ML	PPML^1	ML	PPML^1
Constant	0.682	12.593***	−3.53***	4.945	−0.73	3.639
	(−0.48)	(−3.59)	(−0.56)	(−11.82)	(−0.6)	(−33.31)
Forest Rents (exporter)	0.053*	0.195***	0.089***	0.274***	0.1**	0.319*
	(−0.02)	(−0.03)	(−0.02)	(−0.02)	(−0.03)	(−0.14)
Forest Rents (importer)	−0.104***	−0.326***	−0.064***	−0.193**	−0.078***	−0.24
	(−0.02)	(−0.07)	(−0.01)	(−0.07)	(−0.02)	(−0.27)
Production (exporter)	0.057***	0.18***	0.093***	0.474***	0.06***	0.055
	(−0.01)	(−0.02)	(−0.01)	(−0.03)	(−0.01)	(−0.04)
Production (importer)	0.014*	−0.017	0.009	−0.025**	−0.017**	−0.023
	(−0.01)	(−0.01)	(−0.01)	(−0.01)	(−0.01)	(−0.02)
Consumption (exporter)	−0.023**	−0.027**	−0.006	0.123***	0.018*	0.013
	(−0.01)	(−0.01)	(−0.02)	(−0.03)	(−0.01)	(−0.04)
Consumption (importer)	0.06***	0.117***	0.141***	0.128***	0.055***	0.157*
	(−0.01)	(−0.02)	(−0.01)	(−0.03)	(−0.01)	(−0.07)
GDP per capita (exporter)	0.209***	0.413***	0.562***	0.227***	0.476***	0.869***
	(−0.03)	(−0.04)	(−0.03)	(−0.03)	(−0.03)	(−0.13)
GDP per capita (importer)	0.122***	−0.332***	0.217***	0.077	0.222***	0.028
	(−0.03)	(−0.03)	(−0.03)	(−0.05)	(−0.02)	(−0.06)
Distance between Capitals	−1.126***	−0.887***	−1.206***	−0.675***	−1.318***	−0.89***
	(−0.02)	(−0.02)	(−0.02)	(−0.02)	(−0.02)	(−0.07)
Continuous Countries	0.519***	0.394***	0.339***	0.611***	0.333***	0.888***
	(−0.06)	(−0.04)	(−0.06)	(−0.04)	(−0.06)	(−0.12)
Same Official Language	0.666***	0.772***	0.793***	0.422***	0.620***	0.138
	(−0.04)	(−0.04)	(−0.04)	(−0.05)	(−0.04)	(−0.14)
Free Trade Agreement	−0.038	0.102*	0.223***	1.091***	0.325***	0.369**
	(−0.03)	(−0.04)	(−0.03)	(−0.04)	(−0.03)	(−0.14)
one partner is EU member	0.104*	0.599***	0.028	−0.077	−0.253***	−0.622*
	(−0.05)	(−0.08)	(−0.05)	(−0.1)	(−0.05)	(−0.26)
both partners are EU member	0.457***	0.965***	0.314***	0.394*	0.031	−0.189
	(−0.09)	(−0.13)	(−0.09)	(−0.18)	(−0.09)	(−0.44)
N	57885	21959	71968	28052	66885	27821
Pseudo R^2	0.37	0.651	0.378	0.59	0.376	0.657

Note: PPML^1 = PPML without zero-trade; Standard errors in parentheses; ***, **, and * are significant at the 0.1%, 1%, and 5% level, respectively.

Table 5. 8 Estimation results for the product group ‘wood pulp, newsprint and paper & paperboard’

	Wood Pulp		Newsprint		Paper and Paperboard	
	ML	PPML^1	ML	PPML^1	ML	PPML^1
Constant	−1.113	−1.131	−10.296	8.683	−2.929***	0.471
	(−0.84)	(−46.33)	(−169.7)	(−11.15)	(−0.39)	(−4.06)
Forest Rents (exporter)	0.066	0.586***	−0.022	0.35	−0.102***	0.171***
	(−0.04)	(−0.11)	(−0.05)	(−0.25)	(−0.02)	(−0.05)
Forest Rents (importer)	−0.031	−0.004	−0.026	0.031	−0.038***	−0.017
	(−0.02)	(−0.11)	(−0.02)	(−0.11)	(−0.01)	(−0.02)
Production (exporter)	0.068***	0.125**	0.054***	0.443***	0.027***	0.229***
	(−0.01)	(−0.05)	(−0.01)	(−0.08)	(−0.01)	(−0.02)
Production (importer)	0.008	0.002	−0.014*	−0.027*	−0.016**	−0.028***
	(−0.01)	(−0.02)	(−0.01)	(−0.01)	(−0.01)	(−0.01)
Consumption (exporter)	0.025	0.008	0.000	−0.01	0.3***	0.389***
	(−0.02)	(−0.02)	(−0.01)	(−0.02)	(−0.03)	(−0.03)
Consumption (importer)	0.13***	0.407***	0.162***	0.373***	0.28***	0.435***
	(−0.01)	(−0.05)	(−0.01)	(−0.07)	(−0.02)	(−0.02)
GDP per capita (exporter)	0.113**	0.344***	0.35***	0.087	0.31***	0.411***
	(−0.04)	(−0.06)	(−0.04)	(−0.1)	(−0.03)	(−0.02)
GDP per capita (importer)	0.105***	0.499***	−0.017	0.124	0.073***	−0.074***
	(−0.03)	(−0.05)	(−0.02)	(−0.09)	(−0.02)	(−0.01)
Distance between Capitals	−0.966***	−0.718***	−1.231***	−0.761***	−1.305***	−0.87***
	(−0.03)	(−0.03)	(−0.03)	(−0.05)	(−0.02)	(−0.01)
Continuous Countries	0.716***	0.602***	0.484***	0.954***	0.438***	0.551***
	(−0.07)	(−0.05)	(−0.06)	(−0.09)	(−0.06)	(−0.01)
Same Official Language	0.455***	−0.246***	0.659***	0.305**	0.634***	0.152***
	(−0.05)	(−0.05)	(−0.05)	(−0.1)	(−0.03)	(−0.02)
Free Trade Agreement	0.027	0.203***	0.258***	0.654***	0.246***	0.657***
	(−0.04)	(−0.04)	(−0.04)	(−0.1)	(−0.03)	(−0.02)
one partner is EU member	0.129*	−0.502***	−0.273***	−0.364	−0.207***	−0.199***
	(−0.07)	(−0.11)	(−0.07)	(−0.24)	(−0.04)	(−0.04)
both partners are EU member	0.612***	−0.035	−0.109	0.045	0.381***	0.317***
	(−0.11)	(−0.21)	(−0.12)	(−0.44)	(−0.1)	(−0.06)
N	42253	16168	47377	16701	111673	57319
Pseudo R^2	0.401	0.87	0.355	0.9	0.465	0.869

Note: PPML^1 = PPML without zero-trade; Standard errors in parentheses; ***, **, and * are significant at the 0.1%, 1%, and 5% level, respectively.

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6. Discussion and Conclusion

This PhD thesis has aimed to improve forest sector analysis with a focus on implementing actual econometric findings in economic models. This work was guided by exploring the following research questions: how do supply, demand, and trade behave in international forest products markets, and what do estimated elasticities tell us about these markets? How do wood market models respond to changes in market patterns? Which are the underlying mechanisms for bilateral trade in wood markets? In this section, I will first, discuss the main results of this thesis and answering the research questions. In the following the methodology of this thesis will be discussed and eventually I will conclude and give an outlook about possible future research.

6.1. Research questions and key findings

How do supply, demand, and trade behave in international forest products markets, and what do estimated elasticities tell us about these markets?

Economic theory about market reactions suggests a negative correlation between price and demand of a particular product as well as a positive correlation between income and demand for the same product. These theoretical relationships hold for all the examined forest products in this PhD thesis.

In turn, general economic theory assumes a positive response of supply to price increases. Indeed, the domestic supply of raw wood products observed in chapter 2.4 is significantly positive dependent on price changes, even if the coefficients and the overall coefficient of determination are quite low. Regarding the behavior of trade, theory also suggests negative price elasticities for imports and positive price elasticities for exports. Nevertheless, studies in the course of the present thesis found that imports, as well as exports, are significant negatively dependent on changes in price (see chapters 2 and 3). These results allow the interpretation that first, the supply of raw wood products on the global scale seems to be independent of changes in price, and second, that exports for forest products seem to be driven by demand in international markets. In this context, I was also interested in the difference in market patterns between natural and planted forests, as the latter became more and more important for the roundwood supply (Carle and Holmgren 2008). I found that removals from natural forests do not respond significantly to price changes while the removals from planted forests do have a relatively high positive response to changes in price. This outcome may occur because of the economic motive which seems to be one driving force in planting forests. The correlations between prices and harvest could depend on the share of removals from planted forests in a specific region or even in a specific country. Further research should be aware of such behavior, especially the wood market modelling, as differing between these two origins in wood supply may offer more accurate simulations.

Estimated response in fuelwood supply points out that significant positive effects only occur in high-income countries. This significant positive effect bolsters the assumption, that low-income countries use fuelwood independent of prices, while high-income countries can freely decide which kind of fuel to use. This is in line with the literature on the energy stack behavior: Fuelwood is utilized complementarily and not substitutionally with increasing income (van der Kroon et al., 2013).

In particular, the estimations for lignocellulose-based products (see chapter 3) show that real price and income (GDP) are significant parameters in the explanation of export supply and import demand volumes for these products. Further it could be said that the income development is a constant determinant that is positively correlated with trade of these products over the past 30 years. On the contrary, price developments appear to be volatile and are characterized by structural breaks over the same time horizon. In the time periods from 1992 to 1999 and 2000 to 2007 estimations for price elasticities of dissolving pulp yield insignificant estimates and opposite parameter signs than theory suggests. In addition, the magnitude of coefficient estimates jumps between the different estimation periods.

I can state at this point that estimates of income elasticities appear to be positive significant and estimates of price elasticities appears to be negative significant for import demand, apparent consumption as well as export supply models across all products. An exception forms the mentioned effect of dissolving pulp from 1992 to 1999 and from 2000 to 2007.These findings are in line with the estimates for traditional forest products and lead to the suggestion that export supply models for lignocellulose-based products are highly sensitive to international price competitiveness (Raissi and Tulin 2015) and thus, represent international demand for exports (Jonsson 2012) rather than domestic export supply. The positive income elasticity of export supply, on the other hand, was expected since the development of lignocellulose-based industries requires both capital and expertise resources.

The import demand for lignocellulose-based products tends to be more elastic compared to traditional wood products. This might be an indication that these products have closer substitutes in e.g., textile and chemical markets than products in traditional wood markets.

How do wood market models respond to changes in market patterns?

One key finding of this PhD thesis is that GFPM simulations with inelastic wood supply, as estimated in this thesis, and a separation of forest types seem to lead to results closer to actual historical development (see chapter 2.5). An explanation for this behavior could be that with inelastic price reactions in supply the simulated equilibrium increasingly responds to developments in GDP, which is the main driver of demand in the GFPM. This increasing response to developments in GDP may allow the modified GFPM to follow economic shocks more efficiently. The problem with this result is that a stronger response to GDP shocks implies a risk of overestimation in simulation, compared to the original model. However, as I have shown in chapter 2.5 both models, the original and the modified one, structurally underestimate the developments in history, even though the difference between both models is relatively small.

I also found that the dissolving pulp sector could climb out of its current niche and become a relevant player within the forest-based industries (see chapter 4.4). However, this development strictly depends on a change in market patterns in the coming decades. In a scenario where the growth of a bioeconomy stagnates, the share of the dissolving pulp sector in overall wood-based pulp output would stay constant, while in more sustainable environments the share could rises to 35% or 64% of total wood-based pulp production in 2050. Even though similar dynamic growth patterns could be observed during the last decade, its continuation is at least related to the demand for natural textile fibres, which in turn highly depend on GDP and population developments (Kozlowski et al. 2016). The GFPM does not cover the future behavior of these textile markets, therefore, the simulation results for dissolving pulp can only be seen as potential supply from wood markets.

Another driver that potentially changes market patterns is technological progress. To model this in wood markets, different scenarios about the reduction of required wood input and different levels of digitalization were implemented into the simulations of an emerging bioeconomy (see chapter 4.3.2). Under the paradigm of technological progress, I found that the global increases in dissolving pulp production are not negatively correlated to the production of sawnwood and wood-based panels sectors. While I observe that the global production of sawnwood only changes to a minor extent, the global production of wood-based panels even increases compared to the levels of 2015 in increasingly sustainable environments. In this context, increasing sustainability means that the amount of wood required to produce wood-based panels is incrementally replaced by the growing use of post-consumer wood. Nevertheless, the increasing demand for lignocellulose-based textile fibers and the assumption of technological progress together with economies that focus on regional production led to a shift in the production of dissolving pulp from North America and Europe to Asia until 2050. Practically, this would lead to decreasing importance of North America and Europe in global dissolving pulp markets. Similar shifts can be observed for several other forest products, too. Today, Asia is a net importer of roundwood, sawnwood, as well as paper and paperboard, while North America and Europe are net exporters of these product groups (FAO 2020). The GFPM results suggest that, until 2050, the production of many wood-based products will take place directly in Asia instead of being imported from other continents such as North America and Europe. However, the magnitude of the shifts is product specific: for sawnwood or wood-based panels, the observed effect was in general weaker, as for dissolving pulp or industrial roundwood.

Which are the underlying mechanisms for bilateral trade flows in wood markets?

As mentioned above aggregated trade can be influenced by factors like prices or income. However, analysis for bilateral forest products trade flows depends on several additional parameters. One theory that describes these trade flows is the gravity model of trade where distance and income are the main parameters. Indeed, I found evidence that bilateral trade in wood markets is positively dependent on the income of both partner countries and negatively dependent on the distance between these partners (see chapter 5). Therefore, it could be said that the traditional definition of gravity holds in international wood markets.

However, the structural gravity model also suggests that the GDP of the importing country works as a proxy for total expenditures a country could spend for imports, but within this framework there is room for additional explanatory variables like forests rents and consumption of a specific wood product. Therefore, all three variables should be positively correlated with trade. The results reveal that bilateral trade is significant positive dependent on changes in the consumption of forest products and the GDP in importing countries. In contrast, forest rents in importing countries are negatively significant. Together with the non-significant influence of production in importing countries (which was suggested to be one parameter that describe the degree of competition for wood products), this leads to the conclusion that, contrary to the suggested classification, forest rents in importing countries work as a factor which describe the degree of competition for wood products in the importing country. On the other hand, and within the framework of structural gravity, production, forest rents, and the GDP in the exporting country can be interpreted as part of the production value of the exporter. These variables behave exactly as suggested above and thus, influence trade in a positive way. Further, it seems that within the framework of structural gravity the consumption in exporting countries is a suitable proxy for the market potential of the exporter as it significantly influences the magnitude of trade in a negative way.

In reference to the bilateral market accessibility, I found evidence that it is determined by the distance, a common border, and the existence of free trade agreements between trading partners. Results show that with increasing distance both, the magnitude, and the likelihood of the occurrence of trade, are significantly negatively influenced, while sharing a border increase both components of trade. In general, I found that free trade agreements have a significant positive effect on trade, too. The membership in the EU turns out to be a special case in the context of free trade agreements. I found that it is an advantage for trade activities only if both partners are member of the EU but a disadvantage if only one partner is an EU member. Sharing the same language only increases the likelihood of the occurrence of trade but not its magnitude and can therefore only partly be interpreted as a variable in the structural gravity model which eases market accessibility.

Industrial roundwood processing is noticeably less influenced by factors like rents in the forest sector or free trade agreements compared to paper products. It also holds that, if only one of the trade partners is an EU member, this is an advantage for trade with industrial roundwood, sawnwood, and veneer but it is a disadvantage for trade with paper products. However, if both partners are EU members, forest products trade is always increasing (except for wood pulp and newsprint as in this case this variable does not influence trade).

Using the structural gravity model of trade, I also found that trade patterns of further processed wood products behave differently than trade patterns of wood raw materials. Thus, it could be shown that trade for industrial roundwood increases with lower incomes in the exporting, and higher incomes in the importing country while the reverse relationship is found in the paper and paperboard sector. This effect may be explained by the fact that wood processing industry tends to be in countries with higher income, while low-income countries more likely export the raw materials.

A last point I want to address, is that compared to the traditional gravity model, the structural model provides a broader theoretical background for the estimation of trade relationships. It is also found that past studies, which used the traditional gravity definition, overestimates the aggregated GDP effect on forest sector trade. The structural approach also offers the possibility to include gravity to partial equilibrium models of wood product markets, as these models often use endogenous parameters for production and consumption which are also part of this structural definition of gravity. With the traditional definition, this would not work because partial equilibrium models, like the GFPM, often do not account for the endogenous development of aggregated income, like the GDP.

6.2. Discussion of methods

The key method used in this PhD thesis is the implementation of actual econometric findings in economic models. One problem regarding this method is that results from market observations are implemented into a mathematical model which is derived from theory. The main issue appearing from such an approach is that theory and empirical-data-based analysis might not catch up with each other: Theoretical models are simplified versions of reality that do not represent and include all possible influences on a certain topic. Empirical-data-based analysis that estimates parameters for the use in such models needs to adopt this simplified way of thinking otherwise estimated coefficients might bias the analysis of the theoretical model. The empirical model, therefore, might appear underfitted in a way that it seemingly does not capture all the logic of the data and maybe has low accuracy. However, a well-fitted empirical model will not work in a theoretical model which does not cover and use all relevant variables from data. For example, the demand functions for demand within the GFPM work only with the price and income elasticities. The empirical model for demand functions in wood markets appears to be underfitted with only these two variables. But implementing new variables to the empirical model may influence the coefficients for price and income elasticities which in turn might also influence the theoretical model. If the theoretical model, in turn, cannot be extended by the newly estimated variables it might become biased. There are two solutions for such problems: first, extend the theoretical model, or, second, work with underfitted empirical models (which still possess sufficient explanatory power). For this thesis, the latter is chosen.

Both, empirical and theoretical modelling results are highly dependent on the underlying data which is used for the analysis. This induces another challenge in global wood markets analysis in general and for this PhD thesis in particular: to set up a reliable database. However, on global scale only a few databases exist for the forest sector. The overall reliance on data delivered by a few data bases harbors the risk of possible data errors that are not detected due to missing options for cross checking or referencing.

Estimating price elasticities in markets with storable commodities like wood products can also lead to inaccurate results, because shocks in wood supply can be compensated through storage building. Such behavior influences price mechanism and biases estimations, even if the shock is located some time periods earlier or if it is expected to happen in the future. To tackle this phenomenon, Roberts and Schlenker (2013) have taken an approach implementing shocks in the estimation of supply and demand for agricultural commodities. In forest product markets such shocks could be described, e.g., by calamities like severe weather events (Prestemon and Holmes, 2004, Prestemon and Holmes, 2010 or Kinnucan, 2016).

It is important to mention that economic equilibrium models and their underlying scenario assumptions have several inherent limitations: First, a general limitation for these models is that, even though, these approaches were built for ex-ante analysis, all input data for the model rely on historical developments. This led to the conclusion that the GFPM, its structure and its parameters, cannot be sensitive to possible structural economic shifts or singular economic shocks in future, because it is built with the knowledge of the past and rely on the current state of the world. A second limitation is that the scenario analysis highly depends on assumptions about future developments like population and GDP growth rates from different storylines. A priori, it is not possible to judge about the probability and accuracy of the underlying scenario assumptions. A last but important issue is that the GFPM does not model competing end-product markets, like construction, furniture or, in the case of lignocellulosic fibres, the textile sector.

In contrast to economic equilibrium models, econometric approaches were built to perform ex-post analysis. This also applies to analysis with the gravity model of trade, which is especially good to analyze trade policy in the past. Effects of (large-scale) policy changes in the future, on the other hand, are difficult to be simulated with such models. Therefore, the embedding of the gravity model into partial equilibrium models for forest product markets remains a task for future research.

Despite these limitations, I consider that the approach used for this thesis allows for important insights into the wood product markets' behavior and thus, foster research in the field of forest product modelling to further improve decision making processes.

6.3. Conclusion and Outlook

This PhD thesis aims to improve forest sector analysis by enhancing economic modelling approaches in the face of changing international forest products markets. Several causes can explain changing patterns of wood markets, however, for the purpose of this thesis three main causes were selected: social transformation, technological progress, and developments in markets itself.

To explain the latter, market functions for demand, supply and trade were estimated with an econometrical approach. The results led to the recognition that prices have little influence on the removals from forests. However, a closer look on different types of removals shows that removals from planted forest indeed respond significantly to price changes. This relation might be because planted forests are more often a business cases than natural forests. These results were tested on plausibility by implementing the newly estimated elasticities to a partial equilibrium model, the GFPM. I found that the simulation of this modified GFPM became more accurate with differing wood supply from planted and natural forests and the new price elasticities of demand, supply, and trade compared to the original GFPM model. Future modelling approaches may enlarge the theoretical background for supply and demand functions within their models because the application of econometric models suggest that omitted variables may exist. This assumption is backed by the respective coefficient of determination which is quite low. Other determinants that could be tested for analysis may be material substitution in terms of cross-price elasticities in end-product markets (Jochem et al., 2016) or population growth (Alexandratos, 1995).

It could be said that the structural gravity approach offers a more detailed look about the factors which influence bilateral trade than the traditional gravity model could do. Nevertheless, the GDP as an aggregated factor, still is a powerful parameter to explain trade in the forest sector, while the structural gravity theory, which is first used for wood markets in this thesis, potentially offers new insides in bilateral trade patterns which may help to improve economic equilibrium models for the forest sector.

One effect future research about bilateral trade flows should kept in mind is that some product groups show different behaviors between the possible occurrence and the magnitudes of trade flows. One example I found with this thesis is that the occurrence of aggregated sawnwood trade is not determined by the distance between trade partners, while the magnitude of trade is negatively dependent on this distance. This effect does only hold for this aggregated sawnwood and not for coniferous respectively non-coniferous sawnwood and may result from the fact that aggregated product trade responds differently than disaggregated product trade to external characteristics.

However, in addition to market developments itself, wood product market analysis also needs to consider social transformation and technological progress. If the world would undergo a change in form of a social transformation toward a sustainable bioeconomy, consumption of roundwood could shift from fuelwood or classical paper production towards more efficient production of wood-based panels or lignocellulose-based materials. However, the model results further suggest that such a development must be accompanied with technological progress to reduce the total amount of wood input into the final products. This would generate additional resource potentials for new wood-based products. In scenario simulations, the growth of sawnwood production remains limited compared to the increasing importance of wood-based panels. This is among others due to the decreasing amount of roundwood input in favor of the increasing use of post-consumer wood to produce wood-based panels. Additionally, I found that the dissolving pulp subsector has the potential to outpace at least today's paper pulp subsector. Thereby, the increase in dissolving pulp production may not impact the resource base and production volumes of the sawnwood and wood-based panels sector, because of decreasing energetic use of wood in some scenarios and ongoing digitalization and technological progress that may set free fibre resources that were formerly used for, e.g., paper production. In sum, I can conclude that the current set of wood and wood-based products may be enlarged and diversified in the future. Forest sector modelling should anticipate such developments by introducing the most promising commodities to their frameworks. This PhD thesis takes account of this and includes new product groups such as roundwood from planted and natural forests or lignocellulose-based products.

In a final remark, I want to note two tasks that are left for future research: first, fabricated textile fibres are mainly used domestically by the textile and apparel industries, instead of being traded. I assume that this is also true for lignocellulose-based products. Therefore, an important task for future research would be to estimate price elasticities for, e.g., domestic production and consumption of lignocellulose-based chemical derivatives and textile fibres. However, the major problem to deal with such tasks would be the identification of and access to suitable national production data for a reasonable number of countries. It would also be interesting to extend the existing set of variables for supply and demand equations of lignocellulosic models, e.g., widen the statistical analysis towards the inclusion of cross-price elasticities of substitute products for having a better picture of the competitive market environment. Again, the availability of adequate data is a major hindrance for such an analysis on a global level.

Second, estimations for natural and planted forests show that removals from both kinds of forests behave differently. As it is likely that removals from planted forests gain importance, and forest sector modelling may intend to adopt this differentiation of forest types, data about the price and trade of global wood from different origins should be gathered in future research.

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Authorship contribution

Article:

Supply and demand functions for global wood markets: Specification and plausibility testing of econometric models within the global forest sector

Authors:
Christian Morland, Franziska Schier, Niels Janzen and Holger Weimar

Authorship Contribution System		Scoreboard for: **Christian Morland**	Scoreboard for: **Franziska Schier**	Scoreboard for: **Niels Janzen**	Scoreboard for: **Holger Weimar**	Scoreboard for: **author 5**
Intellectuel Input (planning/disigning/interpreting)		**25**	**15**	**5**	**10**	**0**
No contribution	0					
One detailed discussion	5					
Several detailed discussion	10					
Corresponding longer meetings	15					
Substantial liasons	20					
Colosest possible involvement	25					
Practical Input: Data Caputure		**25**	**5**	**0**	**0**	**0**
No contribution	0					
Small contribution	5					
Moderate indirect contribution	10					
Moderate direct contribution	15					
Major indirect contribution	20					
Major direct contribution	25					
Practicle Input: Beyond Data-Capture		**10**	**5**	**0**	**5**	**0**
No contribution	0					
Minor or brief assistence	5					
Substantial or prolonged assistence	10					
Specialist Input form related Fields		**15**	**5**	**5**	**5**	**0**
No contribution	0					
Brief or routine advice	5					
Specially-tailored assistence	10					
Whole basis of approach	15					
Literary Input (contrib. to first complete draft of manuscript)		**25**	**15**	**5**	**10**	**0**
No contribution	0					
Edited others´ material	5					
Contributed small sections	10					
Contributed moderate proportion	15					
Contributed majority	20					
Contributed virtually all	25					
Total Score:		**100**	**45**	**15**	**30**	**0**

Article:

Estimating supply and demand elasticities of dissolving pulp, lignocellulose-based chemical derivatives and textile fibres in an emerging forest-based bioeconomy

Authors:

Franziska Schier, Christian Morland, Matthias Dieter and Holger Weimar

Authorship Contribution System		Scoreboard for: **Franziska Schier**	Scoreboard for: **Christian Morland**	Scoreboard for: **Matthias Dieter**	Scoreboard for: **Holger Weimar**	Scoreboard for: **author 5**
Intellectuel Input (planning/disigning/interpreting)		**25**	**10**	**10**	**10**	**0**
No contribution	0					
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Several detailed discussion	10					
Corresponding longer meetings	15					
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Practicle Input: Beyond Data-Capture		**10**	**10**	**5**	**5**	**0**
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Specially-tailored assistence	10					
Whole basis of approach	15					
Literary Input (contrib. to first complete draft of manuscript)		**20**	**5**	**10**	**10**	**0**
No contribution	0					
Edited others´ material	5					
Contributed small sections	10					
Contributed moderate proportion	15					
Contributed majority	20					
Contributed virtually all	25					
Total Score:		**95**	**50**	**30**	**30**	**0**

Article:

Modelling Bioeconomy Scenario Pathways for the Forest Products Markets with Emerging Lignocellulosic Products

Authors:
Christian Morland and Franziska Schier

Authorship Contribution System		Scoreboard for: **Christian Morland**	Scoreboard for: **Franziska Schier**	Scoreboard for: **author 3**	Scoreboard for: **author 4**	Scoreboard for: **author 5**
Intellectuel Input (planning/disigning/interpreting)		**20**	**20**	**0**	**0**	**0**
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Several detailed discussion	10					
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Substantial liasons	20					
Colosest possible involvement	25					
Practical Input: Data Caputure		**25**	**20**	**0**	**0**	**0**
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Moderate direct contribution	15					
Major indirect contribution	20					
Major direct contribution	25					
Practicle Input: Beyond Data-Capture		**10**	**5**	**0**	**0**	**0**
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No contribution	0					
Brief or routine advice	5					
Specially-tailored assistence	10					
Whole basis of approach	15					
Literary Input (contrib. to first complete draft of manuscript)		**15**	**20**	**0**	**0**	**0**
No contribution	0					
Edited others´ material	5					
Contributed small sections	10					
Contributed moderate proportion	15					
Contributed majority	20					
Contributed virtually all	25					
Total Score:		**85**	**75**	**0**	**0**	**0**

Article:

The structural gravity model and its implications on global forest product trade

Authors:
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Authorship Contribution System		Scoreboard for: **Christian Morland**	Scoreboard for: **Franziska Schier**	Scoreboard for: **Holger Weimar**	Scoreboard for: **author 4**	Scoreboard for: **author 5**
Intellectuel Input (planning/disigning/interpreting)		**25**	**15**	**10**	**0**	**0**
No contribution	0					
One detailed discussion	5					
Several detailed discussion	10					
Corresponding longer meetings	15					
Substantial liasons	20					
Colosest possible involvement	25					
Practical Input: Data Caputure		**25**	**10**	**0**	**0**	**0**
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Small contribution	5					
Moderate indirect contribution	10					
Moderate direct contribution	15					
Major indirect contribution	20					
Major direct contribution	25					
Practicle Input: Beyond Data-Capture		**10**	**5**	**5**	**0**	**0**
No contribution	0					
Minor or brief assistence	5					
Substantial or prolonged assistence	10					
Specialist Input form related Fields		**15**	**5**	**5**	**0**	**0**
No contribution	0					
Brief or routine advice	5					
Specially-tailored assistence	10					
Whole basis of approach	15					
Literary Input (contrib. to first complete draft of manuscript)		**25**	**15**	**10**	**0**	**0**
No contribution	0					
Edited others´ material	5					
Contributed small sections	10					
Contributed moderate proportion	15					
Contributed majority	20					
Contributed virtually all	25					
Total Score:		**100**	**50**	**30**	**0**	**0**

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Curriculum Vitae

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