Timber market Model for policy-Based Analysis

Figure 1: TiMBA Logo

Documentation of data, parameter, and model structure

authored by TI-FSM

TI-FSM is an authors' collective that jointly developed and program TiMBA.

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Preface

TIMBA is a partial economic equilibrium model for the global forest products market. The model endogenously simulates production, consumption and trade of wood and wood-based products in 180 countries. TIMBA computes the market equilibrium for each country and product in a given period by maximizing the social surplus in the global forest sector. In the equilibrium processes, commodity production, consumption and prices are recursively balanced for each simulation period. TiMBA is a Python-based model with a modular structure build entirely with open-access libraries.

This work is the result of great joint efforts of the forest sector modelling team at the Thünen Institute of Forestry from 2018 to 2024. In recent years, a number of people made important contributions to this work. Without their support, reflection, and constructive criticism, this undertaking would not have been as successful as it turns out to be now. We would like express our gratitude to all of them. In particular, we would like to thank - Pixida GmbH and especially Tobias Hierlmeier for professional support in revising and restructuring the model architecture and code and being valuable help in programming tasks - Thünen Institute Service Centre for Research Data Management and especially Harald von Waldow for providing expertise, consultation and support during the release process - Holger Weimar and Matthias Dieter for the trustful and cooperative working environment, rational support and critical discussion and the opportunity to keep going - Johanna Schliemann for immediate technical support whenever needed - The Thünen Institute of Forestry and its Head Matthias Dieter for providing financial resources over the years

Summary

This working paper details the underlying structure of TiMBA as well as the data and parameters used for modelling. TiMBA is a partial economic equilibrium model for the global forest sector. The market equilibrium is subject to market clearance and constraints balancing raw material, product manufacturing, consumption while limiting international trade (Samuelson 1952). The model structure distinguishes between raw, intermediate and end products. TiMBA differentiates three types of roundwood (wood fuel, coniferous and non-coniferous industrial roundwood), two additional raw products for paper production (other fibre pulp and waste paper), two intermediate products (mechanical and chemical pulp) and eight finished products (coniferous and non-coniferous sawnwoods, veneer sheets and plywood, particle board, fibreboard, newsprint, printing and writing paper, and other paper and paperboards). Except for sawnwoods, intermediate and end products are produced from a mix of coniferous and non-coniferous industrial roundwood. Scenario simulations with TiMBA are guided

by parameters and assumptions on their developments depicting how the forest sector might unfold in the future. Parameters and assumptions are compiled in the model input file. In the model framework, wood products are implicitly treated as perfect substitutes, regardless of their origin, as long as they belong to the same commodity group.

As the optimization of the market equilibrium in a given year does not include an elasticity of substitution, consumption is merely shifted by changes in income and price (Murray et al. 2004). Thus, changes in gross domestic product (GDP) reflecting national income development is an important driver in the model. Since the consumption of wood-based products is positively correlated to income via a positiv elasticity, an increase in income leads to an increase in demand. The supply of roundwood depends on wood prices and the forest development which in return is determined by the growth dynamics of forest stocks, the change in forest area, and harvest volumes. Forest area development and timber supply is coupled to GDP per capita developments based on the concept of the environmental Kuznets curve (Panayotou 1993). comment:<> (CM: Someone please add reference for Murray 2004)

For its calculations, TiMBA relies on projections of GDP and population growth from the Shared Socioeconomic Pathways (SSP). In its basic version, TiMBA uses the assumptions made in the SSP2 scenario "Middle of the road". This scenario describes a world of modest population growth and where social, economic and technological trends continue similarly to historical patterns (Riahi et al. 2017). Price and income elasticities of demand are taken from (**?**). Further exogenous specifications on technology developments (input-output coefficients and manufacturing cost) are estimated based on historical developments from 1993-2020 while information on trade inertia and cost are based on WTO data as provided in the Global Forest Products Model (GFPM) ((Buongiorno 2015); GFPM version 1-29-2017-World500). The base year for the scenario simulations with the current version of TiMBA is 2020. The input data used for simulation with TiMBA needs to be calibrated and provided in a source file prior to model runs. This file is provided together with the model. The calibration procedure is described in Buongiorno (2015) and altered according to (**?**). The input data for calibrating the model are obtained from three global databases: The FAO forestry statistics (FAOSTAT), the FAO Forest Global Resources Assessment (FAO 2020) and the World Bank Development Indicators (World Bank). comment:<> (CM: Wollen wir die Quellen für FAO und Weltbank hier mit angeben oder machen wir das mit Citavi?)

The model output comprises information about production, consumption and trade quantities, and prices as well as forest development. The model concept bases on the formal description of GFPM (Buongiorno 2015; Buongiorno et al. 2003).

Table 1: Model characteristics overview

Model type	Dynamic and static equilibrium market model
Geographical scope	Global (180 countries)
Temporal Dimension	Recursive long term analyses
Products	Raw-, intermediate, end products
Data sources	FAO, FRA, WDI, Comtrade, WTO, IIASA-SSP
Software Implementation	Python 3.9, 3.12
Current code version	TiMBA 1.0.1
Permanent link to code repositiory	https://zenodo.org/records/13842492
Code License	APGL3
Code versioning system used	GitHub, Zenodo
Solver environment and Solver	CVXPY, OSQP

Introduction

This paper provides an overview over the data and parameters used in the Timber market Model for policy-Based Analsis (TiMBA) and gives an introduction to the model structure and specifications. Further, the results from validating the model performance are presented.

TiMBA is a multi-periodic partial economic equilibrium model for the global forest sector. The model simulates production, imports, exports, consumption quantities and prices as well as technological and forest development for 16 commodities and 180 countries. The prices of wood and wood-based products are endogenous to the model. The market equilibrium is subject to market clearance and constraints balancing necessary raw materials and produced wood products and limiting the trade (Samuelson 1952). In the model framework, wood products are implicitly treated as perfect substitutes, regardless of their origin, as long as they belong to the same commodity. As the optimization of the market equilibrium in a given year does not include an elasticity of substitution, demand is merely shifted by changes in income and price (Murray et al. 2004).

TiMBA distinguishes between raw, intermediate and end products (see figure 1). The model structure currently includes three types of roundwood (wood fuel, coniferous and non-coniferous industrial roundwood), two additional raw products for paper production (other fibre pulp and waste paper), two intermediate products (mechanical and chemical pulp) and eight finished products (coniferous and non-coniferous sawnwoods, veneer sheets and plywood, particle board, fibreboard, newsprint, printing and writing paper, and other paper and paperboards). Commodities and commodity aggregates are determined by the definitions of UNECE (2021). Except for sawnwoods, intermediate and end products are produced from a mix of coniferous and non-coniferous industrial roundwood. Production of intermediate and end products is modelled using Input-Output coefficients determining the level of inputs needed for producing one unit of output. The production level depends on raw material prices, costs of manufacturing as well as commodity prices. While the prices of raw materials and intermediate and end-products are simulated endogenously, cost of manufacturing and transport are given exogenously.

Consumption of wood-based products is tied to country-specific income (GDP) and price levels via price and income elasticities taken from (?). In TiMBA, demand for wood-based products is positively correlated to income, thus, an increase in income basically leads to an increase in demand while demand decreases with increasing product price.

The supply of roundwood depends on wood prices and stock volume which in turn is determined by the growth dynamics of forest stock, the change in forest area, and harvest volumes. TiMBA model import from and to one single country to the world. Trade occurs when the price of a product in a certain country exceeds the foreign price plus transport costs or vice versa is lower than the world price. Simultaneously, there is a need for trade due to the scarcity of goods in one country, which leads in an increased demand or, conversely, an increased supply leading to a surplus in another country. This dynamic consequently incentivizes international trade as countries attempt to balance their production and consumption through imports and exports. The difference in production costs and prices between countries further reinforce the need for such trade interactions in order to optimize resource allocation and market equilibrium.

Scenario simulations with TiMBA are guided by parameters and assumptions shaping future developments. The GDP development indicating national incomes is an important driver of change. In its basic version, TiMBA uses the assumptions made in the "Middle of the road" scenario described in "The Shared Socioeconomic Pathways" (the so called SSP2 scenario) to model future GDP developments and population growth. This scenario describes a world of modest population growth and where social, economic and technological trends continue similarly to historical patterns (Riahi et al. 2017). Demand is subject to annual changes following the projected GDP growth and endogenous price developments, so that new prices and income levels shift the demand for wood-based products via elasticities at an annual interval. On the supply side, price and volume elasticities shift the wood supply at an annual interval. Forest area development and thus, stock volume and timber supply are coupled to GDP per capita developments based on the concept of the environmental Kuznets curve (Panayotou 1993). Information on trade inertia and cost are based on WTO data as provided in the GFPM ((Buongiorno et al. 2003); GFPM-base2021 https://onedrive.live.com/?authkey=%21AEF7RY7oAPlrDPk&id=93BC28B749A1DFB6%2117056&cid=93BC2
The base year for the scenario simulations with the current version of TiMBA is 2020. The input data used for simulation with TiMBA needs to be calibrated and provided in a source file prior to model runs. This file is provided together with the model. The calibration procedure is described in (?) and Zhu:2015 and altered according to (?). The input data for calibrating the model are obtained from three global databases: The FAO forestry statistics (FAOSTAT),

the FAO Forest Global Resources Assessment (FAO 2020) and the World Bank Development Indicators (World Bank). The model output comprises information about production, consumption, trade quantities, and prices as well as forest development and technology.

The model concept bases on the formal description of the GFPM (Buongiorno 2015; Buongiorno et al. 2003).

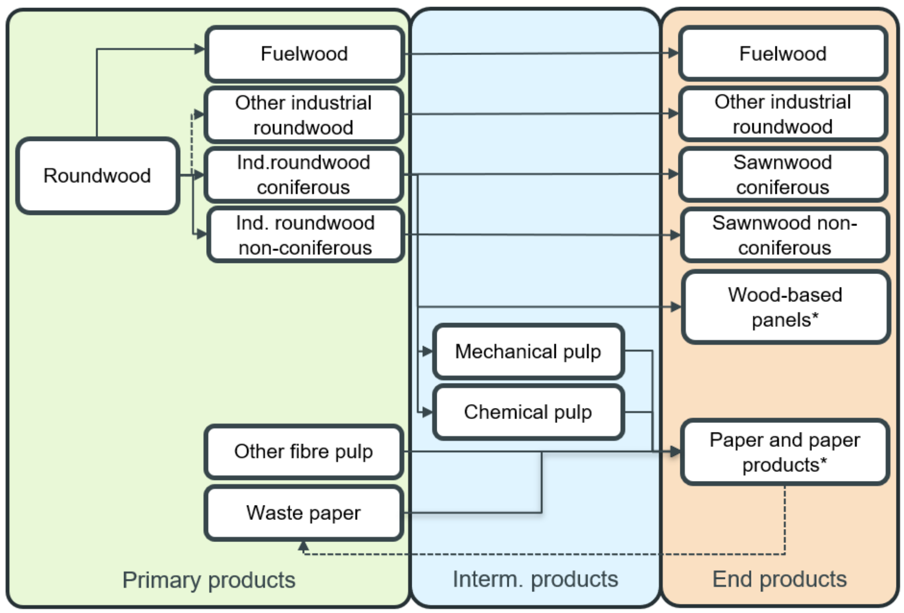

Figure 2: Caption for example figure.

Figure 1: Material flow and product structure in TiMBA. Other fiber pulp and waste paper are solely inputs in the paper sector. Wood residues used as input in the wood-based panel and pulp sectors are not explicitly modeled in TiMBA but implicitly considered by manufacturing coefficients. Double represent the mix of raw materials as input for further processing. Thus, wood-based panels could be made from a single input or a mixture of coniferous and non-coniferous roundwood while paper products could be made from a single input or a mixture of pulp and waste paper. The dotted lines indicate that other industrial roundwood is composite product: While raw data are imported for data calibration, the amounts of coniferous and non-coniferous other industrial roundwood are calculated out from of the total amount of industrial roundwood and summed up as total other industrial roundwood for model simulation. The bold lines indicate, that the product is not further processed before sold as end product.

Model formulation and specifications

TiMBA computes periodic production, import, exports and consumption as well as prices for the forest-based sector considering available forest resource endowment as well as cost, technology and trade constraints. The recursive market model is composed of a static and a dynamic phase.

In the static phase, TiMBA calculates a global equilibrium across products and countries in a given year. The optimization problem is solved for each year by maximizing the economic welfare, defined as the sum of the producer and consumer economic surplus.

In the dynamic phase, changes in the equilibrium conditions (shifts in parameters determining the model outcome such as growing GDP, population or cost) are updated from one period to the next.

The model concept bases on the formal description of the GFPM (Buongiorno 2015; Buongiorno et al. 2003).

The following optimization problem is maximized using the CVXPY package (**?**; **?**) and the OSQP solver (**?**):

$$\begin{aligned}\max_{Z} = &\sum_i \sum_k \int_0^{D_{i,k}} P_{i,k}\left(D_{i,k}\right) dD_{i,k} - \sum_i \sum_k \int_0^{S_{i,k}} P_{i,k}\left(S_{i,k}\right) dS_{i,k} \\ &- \sum_i \sum_k \int_0^{Y_{i,k}} m_{i,k}\left(Y_{i,k}\right) dY_{i,k} - \sum_i \sum_j \sum_k c_{i,j,k} T_{i,j,k}\end{aligned}$$

with P as price, D as demand, S as supply, Y as manufacturing, m as manufacturing costs, T as trade, c as transportation costs and the indices i as the domestic country, j as trade partner country and k as commodity.

Subject to an optimization constraint balancing all material flows along the represented supply chain for each country while accounting for trade:

$$S_{i,k} + Y_{i,k} + \sum_j I_{j,k} = D_{i,k} + \sum_n a_{i,k,n} Y_{i,n} + \sum_j X_{j,k}$$

The equation (tbd) forms for the country (i) and commodity (k) the specific material balance which imposes that the domestic supply of raw materials ($S_{i,k}$) plus the imports ($I_{j,k}$) and the manufactured quantity ($Y_{i,k}$) must be equal to the domestic demand ($D_{i,k}$) of final products plus the input to manufacture other products ($Y_{i,n}$) plus the exports ($X_{j,k}$). $a_{i,k,n}$ depicts the amount of input of product k to produce one unit of product n. The dual values of the material balance (shadow prices) are used as product prices in TiMBA. The model is delivered with different material balance options, which allows the user to control the mathematical form how the constraint is integrated into the optimization.

The chosen form will influence the computation time of the solver and might impact the resulting shadow prices.

Demand:

The demand for wood-based products in TiMBA is correlated to the income (y) and wood prices. The inverted demand function (equation tbd) defines the quantity of demand for end products where D^* is the current demand of product k in country i at last period's price, $P_{i,k,t-1}$ is the last period's price and δ is the price elasticity of demand.

$$P_{i,k}(D_{i,k}) = P_{i,k,t-1} \left(\frac{D_{i,k}}{D^*_{i,k}} \right)^{1/\delta_{i,k}}$$

The demand can be shifted exogenously over the simulation periods to socioeconomic changes using g_y as the growth rate of income, g_D as the exogenous growth rate of demand, α as exogenous parameters to shift the influence of the growth rates and t as the time index.

$$D^*_{i,k} = D_{i,k,t-1} \left(1 + \alpha_y g_y + \alpha_{D,t-1} g_{D,t-1} + \alpha_0\right)$$

Supply:

The supply of roundwood depends on wood prices and forest development which in turn is determined by the growth dynamics of forest stock, the change in forest area, and harvest volumes. The inverted supply function defines the quantity of supply for raw products (equation tbd) where S^* is the current supply of product k in country i at the last period's price and λ is supply price elasticity. Further details on the connection between the supply and the forest stock and area dynamics are provided in the chapter on modelling Forest.

$$P_{i,k}(S_{i,k}) = P_{i,k,t-1} \left(\frac{S_{i,k}}{S^*_{i,j}} \right)^{1/\lambda_{i,k}}$$

To reflect socioeconomic and environmental changes, the supply function can be shifted exogenously over the simulation periods according to equation tbd. In the following equation, g_y represents the income growth rate and g_I depicts the growth rate of forest inventory. β_y is the supply elasticity of income and β_I is supply elasticity relative to the inventory. In TiMBA, the supply elasticity of income is product-specific, differentiating between raw materials sourced from the forest and raw materials for paper and paper product production.

$$S^*_{i,k} = S_{i,k,t-1} \left(1 + \beta_y g_y + \beta_I g_I\right)$$

Forest area development and thus, timber supply is coupled to GDP per capita developments based on the concept of the environmental Kuznets curve ((**?** 2004)). See the section 'Forest' for a more detailed description.

Manufacturing:

Manufacturing of intermediate and end products is determined using country- and product-specific input-output coefficients and manufacturing unit costs. The product and country-specific manufacturing costs are calculated based on the manufactured quantity according to equation (tbd) where $m_{i,k}$ are the manufacturing cost, m^* the current manufacturing cost at the last period's manufactured quantity, and ζ is the elasticity of manufacturing cost with respect to the manufactured quantity.

$$m_{i,k}(Y_{i,k}) = m^*_{i,k,t-1} \left(\frac{Y_{i,k}}{Y_{i,j,t-1}} \right)^{\zeta_{i,k}}$$

The manufacturing costs of each product represent all costs of inputs not explicitly modelled in TiMBA (labour, energy, capital, additional materials), excluding costs of raw materials in a given year and country. For net exporting countries, raw material costs are computed by multiplying the domestic prices of input products by the input-output coefficients. For net importing countries, raw material costs are computed by multiplying the world market price of input products by the input-output coefficients.

The input-output coefficient of each product in a specific year and country states the amount of input necessary to produce one unit of output. The input-output coefficients and manufacturing cost for the base period are obtained by a goal programming procedure and depend on production and trade data from FAOSTAT and exogenous bounds on minimum and maximum input per output and cost (Buongiorno 2015).

Manufacturing costs and input-output coefficients can be exogenously shifted over the calculated periods to reflect technological development. While input-output coefficients are updated in TiMBA, manufacturing costs are developed based on an exogenous growth rate g_m.

$$m^*_{i,k} = m_{i,k,t-1}\,(1 + g_m)$$

Trade:

In TiMBA, all countries import from and export to a virtual buffer region called zy. Since all countries trade via the region zy, bilateral trade fluxes are not represented in the basic model version. The trade in TiMBA depends on the transportation costs ($c_{i,j,k}$), the world price, and trade inertia bounds. The equation (tbd) represents the country and product-specific unit cost of transportation ($c_{i,j,k}$) where c^* is the current transportation cost at the last period's traded quantity and τ the elasticity of transport cost with respect to traded quantity.

$$c_{i,j,k}(T_{i,j,k}) = c^*_{i,j,k,t-1} \left(\frac{T_{i,j,k}}{T_{i,j,k,t-1}} \right)^{\tau_{i,j,k}}$$

In the base period, c_ijk is determined by equation tbd where f_ijk represents the freight cost per unit of transported product k between country i and j. t_jk^X and t_jk^I depict the export and import ad-valorem tax rates, respectively. $P_(ik-1)$ is the world price of the previous period. In TiMBA, the transportation costs plus the world price are carried by the net importing countries. The price for net exporting countries is the world price.

$$c_{i,j,k} = f_{i,j,k} + t_jk^X P_{ik-1} + t_jk^I f_{i,j,k} + P_{ik-1}$$

Further, trade in TiMBA is constrained by trade inertia bounds which depict an exogenous development range based on the traded quantity of the previous period (equation tbd) where T_ijk^L and T_ijk^U are the lower and upper bounds, respectively. For the first period, trade inertia bounds are close to zero to comply with trade quantities from the calibration. To avoid infeasibility, trade inertia bounds are introduced as a flexible constraint in the optimization. In this way, TiMBA can trespass the trade inertia bounds when necessary to find an optimal solution. However, trespasses are sanctioned in the objective function by multiplying the difference by the lower or upper bound with the world prices (equation tbd and equation tbd).

Forest

The development of forest area is simulated exogenously using the environmental Kuznets curve (EKC) approach (**?**; **?** and Krueger:1991). This concept describes an inverted U-shaped relationship between income development and deforestation. Initially, as GDP per capita rises, the rate of deforestation increases until it reaches a turning point. Beyond this point, further increases in GDP per capita result in a decreasing rate of deforestation (Panayotou 1993). Forest stock growth is linked to the development of the area.

$$g_I = \left(1 + \gamma_0 \left(\frac{I_{t-1}}{A_{t-1}} \right)^{\sigma} + \left(\alpha_0 + \alpha_1 y^{'} \right) e^{\alpha_2 y^{'}} \right)$$

with I as forest inventory, A as forest area, σ as elasticity of inventory per unit area, $y^{'}$ as per capita income and γ and α as exogenous parameters to shift the growth rates.

Forest stock evolves over time to a growth-drain equation following Buongiorno (2015):

$$I_t = (I_{-1} + (g_a + g_u + g_u^*)I_{-1}) - pS_{-1}$$

where g_a is annual rate of change of forest area, g_u is periodic rate of forest growth, g_u^* is the adjustment rate of forest growth and pS_{-1} is harvest of previous period .

All necessary data is provided in the supplied input file. The CO2 price cannot be adjusted in the base version of TiMBA. A separate extension will be provided for this purpose.

Countries and Products

For each of the 180 countries considered in the model, TiMBA includes three main sectors along the forest-based value chain: the forestry sector, the wood-processing based industries and the consumers of forest-based products. The forestry sector provides the forest resources to supply fuelwood as well as coniferous, non-coniferous and other industrial roundwood. Forest industries then transform coniferous and non-coniferous industrial roundwood into intermediate and end products which are either used as input for, e.g., paper production or demanded by consumer markets.

Beyond four types of roundwood, the product structure in TiMBA further distinguishes coniferous and non-coniferous sawnwood, plywood and veneer sheets, particle board including OSB, fibre board, newsprint, printing and writing paper and other paper and paper board as end products as well as mechanical and chemical pulp (including semi-chemical pulp) as intermediate and other fibre pulps and waste paper as additional raw materials. For these products TiMBA simulates the production, import, export, consumption and prices for each year and country. As shown in table x, not every product is subject to trade, manufacturing or consumer demand.

Input Data and Parameter

TiMBA uses input data and parameter from various sources. Input data for TiMBA are subject to a goal-programming based calibration procedure tackling data inconsistencies and determining initial input-output coefficients as well as manufacturing cost along the wood-based value adding chain. The model calibration for TiMBA follows the procedure as formally described in Buongiorno (2015) and modified by (**?**). Currently, the calibration procedure is not included int the TiMBA package. The calibrated data are provided in form of an Excel sheet as input for simulations together with the model under https://github.com/TI-Forest-Sector-Modelling/TiMBA

Overview on Input Data

Data on country-specific production and trade volumes of raw, intermediate, and end products are taken from FAOSTAT. Product consumption for the base year is then calculated as production + imports – exports. Further, data on country-specific export values are used to compute the unit product prices in the base year as the total export volume divided by total export quantity stated in constant US $ of 2018 using the GDP deflator from the World Development Indicators database (Code NY.GDP.DEFL.ZS). Unit prices differ for net-importer and net-exporter countries. The unit price of net-importers of a given commodity is the export unit price plus commodity specific freight costs and tariffs.

Data on GDP and population are derived from the World Development database (Worldbank xxx) under the indicator names "GDP (current US$)" and "Population, total" specified by the codes NY.GDP.MKTP.CD and SP.POP.TOTL, respectively.

Tariffs are derived from WTO Integrated Database (IDB) notifications as average of ad valorem duties for the last current year available of the respective reporter country and product on HS-code level 4 – 6. Freight cost are calculated as freight factor times export unit value. Freight factors are taken from the Forest Sector Model GFPM (Buongiorno et al. 2003) (see Table A1), GFPM-base2021 (https://onedrive.live.com/?authkey=%21AEF7RY7oAPlrDPk&id=93BC28B749A1DFB6%2117056&cid=93BC

Data on national Forest Area and Growing Stock on Total Forest Area (in the following Forest Stock) are taken from the FAO Forest Resources Assessment 2020. In case that data on Forest Stock had not been reported in 2020, data were complemented by the authors either by (i) searching for the last available record on Forest Area, (ii) using data on growing stock on naturally regenerated and/or planted forest area or (iii) calculate the Forest Stock from biomass stock data. If none of these information were given, the authors use the entries on living woody biomass density from GlobalForestWatch2000 to derive the Forest Stock of a given country. When the national forest area was reported to be > 1, growing stock on total forest area was required to be at least 1.

Overview on Parameters

Wood products consumption is tied to the product price and income (GDP). These relations are represented by elasticities of demand. Wood production is driven by prices of raw materials as well as the forest stock density of a country and represented by respective elasticities. It is assumed that wood supply equals wood removals from the forest. Supply of wastepaper and other fibre pulp depends on product prices and national income (GDP). All elasticities are summarized in table xx.

Manufacturing of intermediate and end products is determined using country and product-specific input-output coefficients and manufacturing cost. Manufacturing cost of each product represent all cost of inputs not explicitly modeled in TiMBA (labor, energy, capital, additional materials) excluding cost of raw materials in a given year and country. The input-output coefficient of each product in a year and country states the amount of input going into one output. These parameters are determined for each country and product during the model calibration (see above) and depend on production and trade data from FAOSTAT and fixed bounds on minimum and maximum input per output and cost.

Forest stock growth without harvest is negatively correlated to forest density as described by the elasticity of -0.45 (Buongiorno 2015). Via an environmental Kuznets curve the rate of forest area change is linked to the GDP per capita. The effects of GDP per capita and squared GDP per capita on the forest area annual growth rates are again taken from Buongiorno (2015) who estimated the coefficients to be 0.0014 and 0.0898 (see equation xx), respectively. The ratio of wood drain from the forest to harvest is set to be 1.2 expressing that 20% of the above ground biomass is left after harvesting as logging residues while 80% is supplied as roundwood.

For lack of data, some of the parameters had to be set intuitively, based mostly on the dynamic behavior of the model.

Table 2: Items simulated with TiMBA. Product definitions according to FAOSTAT and FAO Forest resources assessment (Quellen)

Item	Item Code	Unit	Supply	Production	Demand	Trade	Price	Growth
Fuelwood	80	1000 m^3	x		x	x	x	
Industrial Roundwood C	81	1000 m^3	x			x	x	
Industrial Roundwood NC	78	1000 m^3	x			x	x	
Oth Industrial Roundwood	82	1000 m^3	x		x			
Coniferous Sawnwood	83	1000 m^3		x	x	x	x	
Non-coniferous Sawnwood	79	1000 m^3		x	x	x	x	
Plywood and Veneer Shets	84	1000 m^3		x	x	x	x	
Particle Board (incl. OSB)	85	1000 m^3		x	x	x	x	
Fibre Board	86	1000 m^3		x	x	x	x	
Mechanical Pulp	87	1000 t		x		x	x	
Semi chem. and Chem. Pulp	88	1000 t		x		x	x	
Other Fibre Pulp	89	1000 t	x	x		x	x	
Waste Paper	90	1000 t	x			x	x	

Item	Item Code	Unit	Supply	Production	Demand	Trade	Price	Growth
Newsprint	91	1000 t		x	x	x	x	
Print. and Writing Paper	92	1000 t		x	x	x	x	
Other Paper and Paperb.	93	1000 t		x	x	x	x	
Forest Area	-	1000 ha						x
Forest Stock	-	million m^3						x

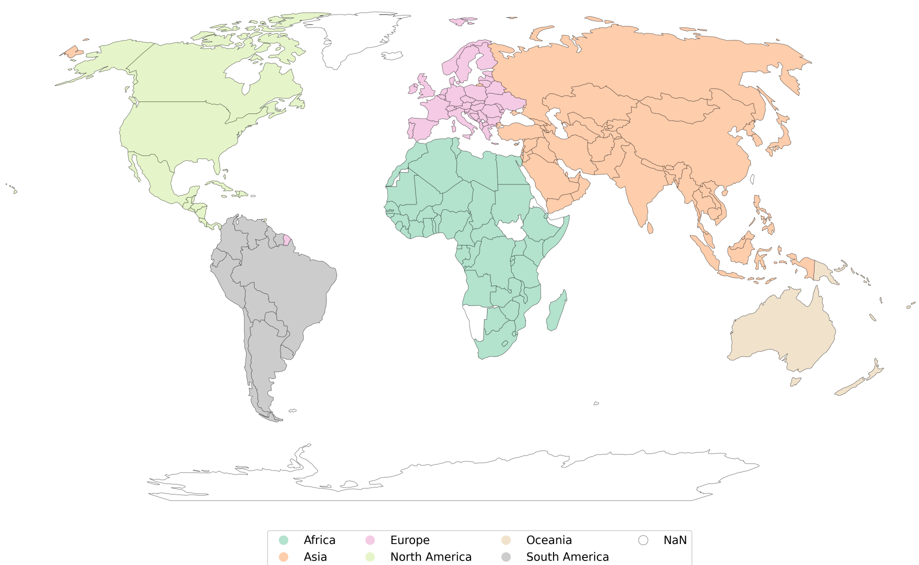

Figure 2: Countries included in TiMBA (continental aggregation according to Table A2)

Table 4: Demand and supply elasticities

	Demand elasticity		Supply elsaticity		
Commodity	price	income	price	income	forest stock
Fiberboard	-0.4629	1.0661			
Fuelwood	-0.1458	0.5680			
Newsprint	-0.1208	0.2371			
Other Paper	-0.1695	0.2283			

	Demand elasticity		Supply elsaticity		
P. & W. Paper	-0.5188	0.3626			
Particle Board	-0.4923	0.7502			
Plywood & Veneer	-0.3534	0.596			
Sawnwood C	-0.3001	0.4409			
Sawnwood NC	-0.1221	0.2162			
Fuelwood			1.0311	-	1.1000
Industrial Roundwood C			1.0738	-	1.1000
Industrial Roundwood NC			1.0440	-	1.1000
Wastepaper			1.0000	0.6700	-
Other Fibre Pulp			1.0000	0.1400	-

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 based on (**?**) taken from GFPM (Buongiorno et al. 2003), GFPM-base2021 (https://onedrive.live.com/?authkey=%21AEF7RY7oAPlrDPk&id=93BC28B749A1DFB6%2117056&cid=93BC

Exogenous Parameter Development

Currently, TiMBA simulates forests and wood product market developments until 2050. Beyond the endogenous equilibrium process, exogenous parameters shift the development pathway form year to year including parameters on country-specific GDP and population growth as well as on as growth rates for country- and product specific input-output ratios and manufacturing costs.

Data GDP and population growth are taken from the "Middle of the road" scenario (SSP 2) described in "The Shared Socioeconomic Pathways" as provided by IIASA data base (QUELLE). Parameters driving forest growth others than GDP per capita are held constant. Future development of input-output coefficients and manufacturing cost were estimated by the authors in a subsequent study based on historical data. Trade activities are contraint by constant trade internia bounds as defined in the GFPM (Buongiorno et al. 2003), GFPM-base2021 (https://onedrive.live.com/?authkey=%21AEF7RY7oAPlrDPk&id=93BC28B749A1DFB6%2117056&cid=93BC

Computer software

After linear approximation of the demand, supply and cost functions (2), (3) and (7), the objective function (1) is quadratic in D, S, Y and T. The equilibrium in a given year is calculated by solving a quadratic optimization problem with linear constraints. The solution is computed with the ... solver (QUELLE). A current version of the TiMBA software together with calibrated input data set (scenario_input) are available here: https://github.com/TI-Forest-Sector-Modelling/TiMBA

TiMBA was subject of an extensive validation process which was designed to assure the quality and functionality of the model. More information about the valiation process and results will be published seperatly and following soon.

Validation

Projection / historic data replication

Inter-model comparison

Economic shocks / economic behaviour

Annex

Table A1: Freight cost of shipping one unit of commodity from origin country to destination country

Commodity	Freight Cost
IndRoundNC	32
SawnwoodNC	50
Fuelwood	14
IndRound	17
OthIndRound	-
Sawnwood	23
Plywood	22
ParticleB	10
FiberB	15
MechPlp	37
ChemPlp	44
OthFbrPlp	109
WastePaper	33
Newsprint	28
PWPaper	52
OthPaper	55
IndRoundNC	37
IndRound	20
Newsprint	22

Table A2: ISO3-Codes of the 180 countries included into TiMBA grouped in continental aggregates

Africa	Asia	Europe	North and Central America	Oceania	South America
AGO	AFG	ALB	ANT	AUS	ARG
BDI	ARE	AUT	BHS	COK	BOL
BEN	BGD	BEL	BLZ	FJI	BRA
BFA	BHR	BGR	BRB	NCL	CHL
BWA	BRN	BIH	CAN	NZL	COL
CAF	BTN	CHE	CRI	PNG	ECU
CIV	CHN	CZE	CUB	PYF	GUF
CMR	CYP	DEU	DMA	SLB	GUY
COD	IDN	DNK	DOM	TON	PER
COG	IND	ESP	GTM	VUT	PRY
CPV	IRN	FIN	HND	WSM	SUR
DJI	IRQ	FRA	HTI	URY	
DZA	ISR	GBR	JAM	VEN	
EGY	JOR	GRC	LCA		
ETH	JPN	HRV	MEX		
GAB	KHM	HUN	MTQ		
GHA	KOR	IRL	NIC		
GIN	KWT	ITA	PAN		
GMB	LAO	LUX	SLV		
GNB	LBN	MKD	TTO		
GNQ	LKA	MNE	USA		
KEN	MDV	NLD	VCT		
LBR	MMR	NOR			
LBY	MNG	POL			
LSO	MYS	PRT			
MAR	NPL	ROU			
MDG	OMN	SRB			
MLI	PAK	SVK			
MOZ	PHL	SVN			
MRT	PRK	SWE			
MUS	QAT				
MWI	SAU				
NER	SGP				
NGA	SYR				
REU	THA				
RWA	TLS				
SDN	TUR				
SEN	VNM				
SLE	YEM				
SOM					
STP					
SWZ					
TCD					

Africa	Asia	Europe	North and Central America	Oceania	South America
TGO					
TUN					
TZA					
UGA					
ZAF					
ZMB					
ZWE					

Table A3: List of 180 countries included into TiMBA with their respective country codes in the model

Algeria	El Salvador	Maldives	St.Vincent/Grenadines
Afghanistan	Equatorial Guinea	Mali	Sudan
Albania	Estonia	Martinique	Suriname
Angola	Ethiopia	Mauritania	Swaziland
Argentina	Fiji Islands	Mauritius	Sweden
Armenia	Finland	Mexico	Switzerland
Australia	France	Moldova, Republic	Syrian Arab Republic
Austria	French Guiana	Mongolia	Tajikistan
Azerbaijan,Republic	French Polynesia	Montenegro	Tanzania, United Rep of
Bahamas	Gabon	Morocco	Thailand
Bahrain	Gambia	Mozambique	Timor-Leste
Bangladesh	Georgia	Myanmar	Togo
Barbados	Germany	Nepal	Tonga
Belarus	Ghana	Netherlands	Trinidad and Tobago
Belgium	Greece	Netherlands Antilles	Tunisiav
Belize	Guatemala	New Caledonia	Turkey
Benin	Guinea	New Zealand	Turkmenistan
Bhutan	Guinea-Bissau	Nicaragua	Uganda
Bolivia	Guyana	Niger	Ukraine
Bosnia and Herzegovina	Haiti	Nigeria	United Arab Emirates
Botswana	Honduras	Norway	United Kingdom
Brazil	Hungary	Oman	Uruguay
Brunei Darussalam	India	Pakistan	USA
Bulgaria	Indonesia	Panama	Uzbekistan

Burkina Faso	Iran, Islamic Rep of	Papua New Guinea	Vanuatu
Burundi	Iraq	Paraguay	Venezuela, Boliv Rep of
Cambodia	Ireland	Peru	Viet Nam
Cameroon	Israel	Philippines	Yemen
Canada	Italy	Poland	Zambia
Cape Verde	Jamaica	Portugal	Zimbabwe
Central African Republic	Japan	Qatar	
Chad	Jordan	Réunion	
Chile	Kazakhstan	Romania	
China	Kenya	Russian Federation	
Colombia	Korea, Dem People's Rep	Rwanda	
Congo, Dem Republic of	Korea, Republic of	Saint Lucia	
Congo, Republic of	Kuwait	Samoa	
Cook Islands	Kyrgyzstan	Sao Tome and Principe	
Costa Rica	Laos	Saudi Arabia	
Côte d'Ivoire	Latvia	Senegal	
Croatia	Lebanon	Serbia	
Cuba	Lesotho	Sierra Leone	
Cyprus	Liberia	Singapore	
Czech Republic	Libya	Slovakia	
Denmark	Lithuania	Slovenia	
Djibouti	Luxembourg	Solomon Islands	
Dominica	Macedonia	Somalia	
Dominican Republic	Madagascar	South Africa	
Ecuador	Malawi	Spain	
Egypt	Malaysia	Sri Lanka	

Parameter list

Table A4: List of input paramters for TiMBA for each model domain

Forest	Supply	Transportation	Demand	Manufacturing
gdp_per_capita_base_period	price	freight_cost	price	net_manufacturing_cost
forest_stock	quantity	import_ad_valorem_tax_rate	quantity	quantity
growth_rate_forest_stock	elasticity_price	export_ad_valorem_tax_rate	elasticity_price	elasticity_price

Forest	Supply	Transportation	Demand	Manufacturing
elasticity_growth_rate_forest_stock	elasticity_gdp	quantity	elasticity_gdp	
forest_area	elasticity_stock	elasticity_trade_exporter	elasticity_expectations	
forest_area_growth_rate	elasticity_area	elasticity_trade_importer	lower_bound	
linear_gdp_forest_area_growth_rate	elasticity_fourth	trade_inertia_bounds	upper_bound	
exponential_gdp_forest_area_growth_rate	elasticity_fifth	price		
fraction_fuelwood	elasticity_sixth	elasticity_price		
ratio_inventory_drain	elasticity_respect_previous_p			
max_ratio_inventory_drain	lower_bound			
CO2_growing_stock	upper_bound			
price_CO2	last_period_quantity			
alpha				
gamma				
periodic_growth_rate_of_forest_area				
forest_growth_without_harvest				
supply_from_forest				

Table A5: List of input parameters exogenously shifted over the simulation horizon to reflect socio-economic, political, and environmental dynamics

Forest	Supply	Transportation	Demand	Manufacturing
growth_rate_stock	elasticity_price	change_freight_cost	elasticity_price	growth_rate_net_manufacture_cost
growth_rate_area	growth_rate_value	change_import_tax_rate	growth_rate_value	change_input_output
growth_rate_gdp	growth_rate_gdp	change_export_tax_rate	growth_rate_gdp	
adjustment_endogenous_growth_rate_stock	elasticity_gdp	exogenous_growth_rate_export_trade_shift	growth_demand_expected	
elasticity_growth_rate_stock_on_area	growth_rate_elasticity_shift	elasticity_trade_exporter_shift	growth_lower_bound	
growth_rate_linear_GDP_forest_area	growth_rate_exogenous_shift	exogenous_growth_rate	elasticity_import_gdp_trade_shift	
growth_rate_squared_GDP_forest_area	growth_rate_sixth	elasticity_trade_importer_shift	growth_rate	
fraction_fuelwood	growth_rate_upper_bound	trade_inertia_bounds		
ratio_inventory_drain				
max_ratio_inventory_drain				
price_CO2				

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