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Modelling of uncertainty in the economic development of the Norwegian forest sector

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A B S T R A C T

Quantitative forest sector modelling includes many model parameters that are treated as being deterministic in the modelling framework, but are in reality often highly uncertain. Few studies have addressed the impacts of this uncertainty and the main objectives of this article are to quantify major market uncertainties in the Norwegian forest sector and analyse their impacts on the results of a forest sector model study for Norway. The uncertainties are derived from historical time series of the prices and exchange rates for international forest products, and their possible impacts are addressed by applying a Monte Carlo approach. A probabilistic approach in modelling is found to have significant impacts on harvest and forest industry production levels. When uncertainty is included, the relative standard deviation for modelled harvest levels varies from 15% to 45%, while for forest products the standard deviations vary from 30% to 80%. We conclude that the most important uncertainty factor for the Norwegian forest sector is the development of international forest product markets, and improved data on demand should be given high priority in future forest sector modelling development.

Introduction

The forest sector, i.e. forestry and forest industries together, is undergoing a major transition. One of the most prominent changes is the reduced demand for printing paper in industrialized countries as a result of competition with digital media (Bolkesjø et al., 2003; Hetemäki and Hurmekoski, 2016; Latta et al., 2016). In addition, relocation of forest industries to low-cost countries is heavily influencing the economics of the forest sector. Price impacts of these changes are shown in Fig. 1, which also illustrates that the economic development of the forest sector is generally highly uncertain. However, most quantitative forest sector analyses and outlook studies based on forest sector modelling largely ignore this uncertainty by using deterministic approaches (Buongiorno, 1996; Latta et al., 2013; Toppinen and Kuuluvainen, 2010).

Forest sector models used to analyse the economic development of forest products' value chains rely on a large set of model parameters that are either relatively well known or based on expert judgements or statistical estimations with varying precision. Sensitivity analysis is the common approach to explore the importance of uncertainty, and is used in several forest sector studies to explore impacts of risks; for example in analysing impacts of changes in tax levels (Buongiorno et al., 2012), demand profiles for forest products (Moiseyev et al., 2014), or introducing new products such as biofuels (Kallio et al., 2018; Mustapha et al., 2017a; Mustapha et al., 2017b; Sjølie et al., 2015; Trømborg et al., 2013). However, sensitivity studies exploring the impacts of just one or a few parameter values normally exclude synergy effects between different parameters, which may lead to over- or under-estimation of the impacts on the system.

Kallio (2010) is the first study to introduce uncertainty parameters in forest sector modelling and addresses the underlying uncertainty related to the growth rate of the standing timber stock, the stock and price elasticities of wood supply, the world market prices, and transportation costs, using Monte Carlo simulations. She also analysed how different scenarios for energy prices and stochastic price developments for forest products, as well as change in forest conservation policy, affected the model outcome, and concluded that uncertainty in the basic parameters was of less importance than scenario uncertainties.

As described by Chudy et al. (2016), the procedure for investigating uncertainties in the forest sector modelling should preferably involve the following steps: First, determine which parameters are most important to include and make simplifications necessary for their

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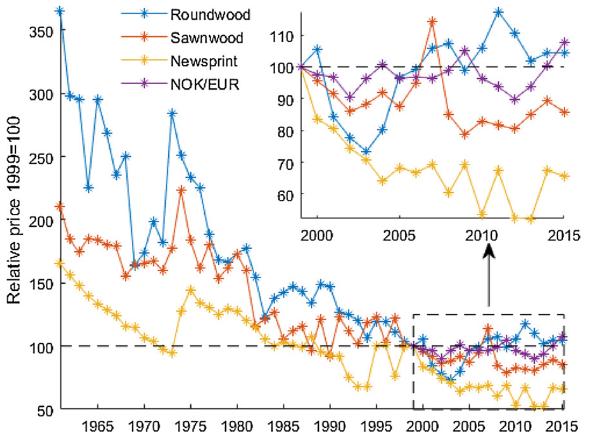

Fig. 1. Historical price development for roundwood, sawnwood and newsprint for the period 1961–2015 and the NOK/EUR exchange rate for the period 1999–2015 (in 2013 prices, adjusted for inflation according to the Norwegian consumer price index).

inclusion in a deterministic model; second, perform sensitivity analyses to identify those parameters which are most important; third, provide probability distributions for these most important parameters based on historical variation; next, apply the probability distributions in Monte Carlo simulations until convergence; and finally, analyse the model results.

A major share of the production in the Norwegian forest industries is exported. A large fraction of the wood consumption in the Norwegian pulp and paper industries has traditionally been imported, whereas Norway now has a significant net export of pulpwood and wood chips. The Norwegian forest sector is thus vulnerable to market developments such as changes in exchange rates and export prices, and consequently, the main objective of this study is to quantify how uncertainties in these parameters might affect the developments in the Norwegian forest sector.

Based on historical data, we quantify the annual fluctuations in the foreign exchange rates (NOK/EUR) and export prices for sawlogs (pine and spruce), pulpwood (pine and spruce), fibreboard, particleboard, sawnwood (pine and spruce), and newsprint. We then apply the forest sector model NTMIII calibrated for Norway (Trømborg and Sjølie, 2011) to quantify how these uncertainties affect the equilibrium prices and quantities of the Norwegian forest sector, and the underlying uncertainties. NTM III is a multi-periodic, spatial, partial equilibrium model. The theoretical basis for the model is that of spatial equilibrium in competitive markets as first solved by Samuelson (1952) for several commodities. NTMIII is based on the principles of the Global Trade Model (GTM) (Kallio et al., 1987), which is the basis for several national models with regional disaggregation, such as the Finnish Forest Sector Model (Ronnila, 1995) and previous versions of the Norwegian Trade Model.

Through Monte Carlo simulations, the impacts of the fluctuations on consumption, production, harvest and prices in Norway were analysed. Similar to Kallio (2010), we include analysis of the time-dependent impacts of the uncertain factors, with the main focus on initial impacts as well as impacts 8 years into the future, which corresponds to the years 2017–2025.

Method

Forest sector model specifications

NTM has been developed in two previous stages by Trømborg and Solberg (1995) and Bolkesjø et al. (2005), before the current and third version named NTMIII (Trømborg and Sjølie, 2011). NTMIII includes a more detailed representation of harvesting residues as well as the bioenergy market compared to previous versions of the model. In this study, the reference year is updated using data described in Mustapha (2016), and Trømborg and Sjølie (2011). The NTM model has previously been used to analyse impacts of forest conservation (Bolkesjø et al., 2005), increased use of bioenergy (Trømborg et al., 2007; Trømborg and Solberg, 2010), transport cost changes (Trømborg et al., 2009), and establishment of wood-based biofuel plants (Trømborg et al., 2013).

The NTMIII is recursive dynamic and largely based on the principles of the Global Trade Model (GTM) (Kallio et al., 1987), with harvest, production, consumption, maintenance, transport and prices solved simultaneously for each period by maximizing, for each period, the sum of consumer and producer surpluses. As shown by Samuelson (1952), this maximizes the economic utility and simulates the economic development of the sector assuming perfect competition. Latta et al. (2013) gives a review of historic developments in forest sector models.

The model consists of four components: (1) consumer demand, (2) timber supply, (3) industrial production, and (4) trade. Timber supply is determined by supply elasticities, changes in growing stock, and price of timber in the industry. The amount of final product produced in the factories is modelled by input-output coefficients of timber and intermediate industrial products, and exogenous input prices like the costs of labour and energy. The production costs and product prices determine the volume of production. The demand for final products is determined by regional consumer demand profiles, demand elasticities, and product prices. Finally, trade between regions for raw materials, intermediate products and final products occurs until the price difference between regions equals the transport cost.

The model is multi-periodic, but the model optimization is static as it gives an equilibrium solution for each future period modelled. The model solution for a particular period is used to update the model input for the subsequent period for the data on market demand, timber supply, prices, and changes in production costs and available technologies. Thereafter, a new equilibrium is computed subject to the new demand and supply conditions, new technologies, and new capacities. As such, the dynamic changes from year to year are modelled using a forward recursive programming approach, meaning that the long-run spatial market equilibrium problem is broken up into a sequence of short-run problems, one for each year. Hence, the modelling is based on the assumption that the decision makers in the economy have imperfect foresight.

In total, the model consists of 21 regions, of which 19 are in Norway, one region covering Sweden and one region representing the rest of the world. The model contains six wood categories (pine, spruce and non-coniferous for both sawlogs and pulpwood), nine intermediate products for use in industry and 12 final products for end consumption. A full description of the data and model will occupy too much space here, but the main principles are given below. The object function is:

$$Max_{q_f^i,h_w^i,y_l^i,e_k^{ij}} \left\{ \sum_{if} \varepsilon^i \rho_f q_f^i \left[\left(1-\frac{1}{\tau_f}\right)(1-N_f^i(0,\vartheta_f)) + \frac{1}{2q_{f0}^i \tau_f} q_f^i \right] - \sum_{iw} \varepsilon^i \int_0^{h_w^i} (\alpha_w^i h_w^{i\beta_w^i}) dh_w^i - \sum_{il} \varepsilon^i c_l^i y_l^i - \sum_{il} \varepsilon^i \varphi_l^i y_l^i - \sum_{ijk} \varepsilon^i D_k^{ij} e_k^{ij} \right\} \quad (1)$$

where the indexes i and j refer to regions, k to products (final products, intermediate products and roundwood categories), f to final products, w to roundwood categories, and l to production activities. ε^i represents the currency exchange factor for region i. Term 1 is the inverse demand function. ρ_f is the base price, τ_f is the price elasticity, $N_f^i(0,\vartheta_f)$ is the probability distribution with mean of zero and a relative uncertainty ϑ_f, q_f^i is the new consumption, and q_{f0}^i is the reference consumption of product f in region i. $\alpha_w^i h_w^{i\beta_w^i}$ (term 2) represents the timber supply, with h_w^i as harvest level of roundwood w in region i. β_w^i is the econometrically estimated roundwood supply elasticity and α_w^i is calculated