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

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# Abstract

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.

Keywords: Forest sector modelling; Monte Carlo; Norway; Partial equilibrium; Short-term uncertainty; Uncertainty

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# 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 Figure 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 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.

The rest of the paper is organized as follows: In Chapter 2 methodology and data are described, in Chapter 3 the results are presented, and in Chapter 4 they are discussed and main conclusions are drawn in Chapter 5.


Figure 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).

# 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:

where the indexes and refer to regions, to products (final products, intermediate products and roundwood categories), to final products, to roundwood categories, and to production activities. represents the currency exchange factor for region. Term 1 is the inverse demand function. is the base price, is the price elasticity, is the probability distribution with mean of zero and a relative uncertainty, is the new consumption, and is the reference consumption of product in region. (term 2) represents the timber supply, with as harvest level of roundwood in region. is the econometrically estimated roundwood supply elasticity and is calculated with use of and base-year harvest; a further description of and is shown in Bolkesjø et al. (2005). (term 3) and (term 4) represent the exogenous part of the marginal industrial production costs, with as an input cost, as maintenance cost, and as the produced quantity of production activity in region. (term 5) represents trade of product between regions and, with as the unit transportation cost and as the quantity that is exported from region to region.

The objective function solution is found subject to the following constraints:

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where index represents all production activities related to pulp and paper and represents recycled paper. and are final product and roundwood inputs, respectively, for production activity. is the capacity for production activity in region, and, finally, is the predetermined recycling rate for final products in region.

Equation (2) ensures that consumption of final products is equal to the difference between production and trade in each region. Equation (3) ensures that roundwood harvest is equal to the difference between the use of roundwood in the production and trade for each region. Equation (4) ensures that the production of pulp and paper does not exceed production capacity, and equation (5) ensures that the total use of recycled paper does not exceed a predetermined recycling rate share of the total paper consumption. Finally, export, consumption, production and harvest are non-negative endogenous variables for every product in every region (equation (6)). To find the optimal solutions for the object function (1) under constraints (2)–(6), we used the General Algebraic Modelling System (GAMS) (GAMS Development Corporation, 2017), with CONOPT (CONOPT, 2017) as the nonlinear solver.

## Estimating uncertainty

The observed historical values and quantities of forest products in the FAOSTAT database (FAOSTAT, 2017) were used for quantification of parameter uncertainties. First, the price time series were adjusted for inflation by using the consumer price index of Norway. Then ordinary least squares regression was applied to identify trends, and the annual differences between the estimated least square trend line and the historical deflated prices were calculated. The standard deviations of these differences were defined as the short-term variations.

Uncertainty regarding foreign exchange rates was calculated in the same way using the exchange rate data from Norges Bank (2017).

## Monte Carlo simulations

Monte Carlo simulation is a simple method for addressing uncertainty in large models with many parameters (Metropolis and Ulam, 1949) which is rarely used in forest sector models (Kallio, 2010). The algorithm starts by drawing a random value for every uncertain parameter and running a simulation. Then the process repeats until the result satisfies a predefined convergence criterion. In this study, Monte Carlo simulations are performed by drawing random samples from the assumed probability distribution (Table 1) of world market prices for spruce and pine sawnwood, newsprint, fibreboard, and particleboard, and exchange rate. The heuristic rule used to decide satisfactory convergence was that the mean of variable in question did not change more than 0.1% after 1000 new repetitions were included in the dataset. For each simulation, a sample from the assumed normal distribution was randomly chosen.

## Data

The data used in the analysis of historical variations (section 3.1) was collected from the FAOSTAT database (FAOSTAT, 2017) and Norges Bank (2017). The prices for sawnwood, particleboard, fibreboard and newsprint from the FAOSTAT database (FAOSTAT, 2017) were used to calculate the Norwegian product prices for the period 1961–2015, assuming that the Norwegian export values per unit (export values divided by export quantities) reflect the real Norwegian product prices. Data for the exchange rate were obtained from Norges Bank (2017) for the period 1999–2015.

A vital assumption made here is that historical prices of forest products in Norway are representative for the uncertainty in the model. The historical prices were adjusted for variations caused by inflation and linear trends before the uncertainty calculation. Fitting the observed historical annual prices by applying least squares analysis, the linear trends were obtained. When subtracting the linear trend from the historical prices we found the basis for the uncertainty analysis, where the uncertainty is calculated as the year-to-year variation. Uncertainty in exchange rate was similarly calculated from the year-to-year variations, but no trends were identified.

## Scenarios

The model analyses quantify the impacts of uncertainty in three scenarios: (i) international forest products prices, (ii) exchange rates for the Norwegian currency (NOK) and (iii) uncertainty related to (i) and (ii) combined. The modelled period is 2017–2025 and like (Kallio, 2010) we consider the accumulation of uncertainty over the modelled period. NTM is executed in deterministic modus for the first five-year period (2013-2016), and then the uncertainties are added in the next nine simulated years (2017-2018). The reason for doing this was to enable the investigation of both uncertainties in parameters that are normally considered given, and the short-run implication of those parameters.

When analysing uncertainty in international forest products prices, we assume that Norwegian forest industries are price takers in the international market since the Norwegian consumption and production of final forest products are very small compared to the total world production (FAOSTAT, 2017). Uncertainty in the world market prices is implemented in our study as a vertical shift in the inverse demand function (term 1 in function (1)). represents the relative uncertainty of final product. Two scenarios are analysed using this approach: first, only sawnwood world market prices are varied (SAW), followed by a variation in world market prices of fibreboard, particleboard and newsprint (PROD).

In the analysis of exchange rate uncertainties (EXC), the exchange rate is modelled as a scaling factor which scales all prices and costs in the Norwegian regions, similar to the approach used by Kallio et al. (2004). The exchange rate (parameter in equation (1)) is implemented with the number 1 for the regions outside Norway and a higher or lower number for the Norwegian regions, which represents per cent differences in the Norwegian exchange rate. This implementation ensures that a change in the exchange rate influences trade, demand and production for Norwegian producers and does not directly affect the parameters in the regions outside Norway.

In the last scenario (ALL), uncertainty is implemented for all parameters specified in Table 1. One assumption applied here is that the parameters are uncorrelated in their variation, even though they may be correlated in reality.

# Results

## 3.1 Historical variation and uncertainty calculations

Figure 2 (a, c, e, g) shows historical prices for sawnwood, newsprint, particleboard and fibreboard, corrected to real-term 2013 prices. The prices for sawnwood, newsprint and particleboard have declined substantially since the mid-1960s, while fibreboard prices increased slightly during the 1990s and 2000s. The price changes are either a consequence of real price change or related to changes in the quality of the average product. Figure 2 (b, d, f, h) shows the trend prices (stippled line) in order to visualize the year-to-year variations. The average historical price variation is highest for fibreboard, while sawnwood, particleboard and newsprint display similar average variation.



Figure 2. Historical prices for sawnwood (a, b), fibreboard (c, d), particleboard (e, f) and newsprint (g, h) used in uncertainty analyses. Price (NOK/m3) is adjusted for inflation to 2013 levels (a, c, e, g). The graphs (a, c, e, g) show the trend line (stippled), and the graphs (b, d, f, h) show the year-to-year difference in price, adjusted for the trend line. One standard deviation from the average year-to-year variation is shown (stippled).

The assumption of normal distribution is addressed in Figure 3 showing normal probability plots for the historical year-to-year variation of sawnwood, newsprint, fibreboard and particleboard prices, and normal probability plots for the change in the exchange rate. Variation in sawnwood prices and the exchange rate appear to follow a normal distribution, but the fibreboard and newsprint might have shorter tails. The same is true for particleboard, albeit the trend is observably weaker. Even though the year-to-year variation does not follow a perfect normal distribution, it is assumed to be normally distributed for methodological purposes in this study.



Figure 3. Normal probability plots for the historical year-to-year variation for sawnwood, newsprint, fibreboard and particleboard price (Figure 2) and normal probability plots for the change in the NOK/EUR exchange rate are shown. Normal distribution implies that all historical variation (blue crosses) should intercept the red line.

Table 1 shows the average prices in the reference year, the identified standard deviations from Figure 2 and the exchange rate. The price of fibreboard has the highest standard deviation, whereas the standard deviation of the exchange rate is low. Price variation may be related to the change in the product quality.

**Product Mean value Std Probability Source
[NOK/unit] [%] distributions**

Spruce sawnwood 1510 13 Normal (FAOSTAT, 2017)

Pine sawnwood 1610 13 Normal (FAOSTAT, 2017)

Newsprint 3250 11 Normal (FAOSTAT, 2017)

Particleboard 2024 14 Normal (FAOSTAT, 2017)

Fibreboard 3038 30 Normal (FAOSTAT, 2017)

Exchange rate 7.8 5.1 Normal (Norges Bank, 2017)

Table 1. The historical mean values and standard deviation used in the Monte Carlo simulations. All parameters are assumed to be normally distributed for main forest products and the exchange rate (NOK/EUR). It is assumed that the price of pine and spruce sawnwood has the same standard deviation.

Table 2 displays the correlations between the addressed parameters. High correlation in the parameter values implies that correlation needs to be accounted for in the subsequent analysis. However, the historical prices for sawnwood, particleboard, fibreboard and newsprint, and the exchange rate are mostly correlated to a low extent (<0.50). The highest observed correlation is between newsprint and sawnwood (0.51). This may reflect a causality relationship, but also that both the price of sawnwood and newsprint are linked with the exchange rate and that bi-products from sawmilling represent a vital input into the pulp production used for newsprint production.

**Product Sawnwood Fibreboard Particleboard Newsprint Exchange rate**

Sawnwood 1.0 0.49 0.15 0.51 0.32

Fibreboard 1.0 0.39 0.20 0.11

Particleboard 1.0 -0.05 0.26

Newsprint 1.0 0.40

Exchange rate 1.0

Table 2. Correlation matrix of the historical prices for main forest products and the exchange rate (NOK/EUR).

## Model simulation results

Simulation results without variation in the parameters are used as a reference in order to quantify the uncertainty of model results caused by the observed historical variation in the addressed parameters. There are minor deviations between model-simulated prices and historical prices displayed in Table 1, as the 1st year simulated with uncertainties is 2017 whereas the reference model year is 2013 and the small error is related to the calibration of the model. The modelled 2017 prices are, however, within the standard deviation of the observed 2013 prices.

An outline of the total variation in 2017 (1st year) and 2025 (8th year) is shown in Figure 4, with the mean, median as well as the 5th percentile and 95th percentile resulting from the forest sector model Monte Carlo simulations. Due to the aggregation of uncertainty from the annual sampling, the variability increases from 2017 to 2025. The highest modelled uncertainty in prices is found for sawlogs and sawnwood. According to our findings, the assumed uncertainty related to exchange rates and international forest products markets causes fairly high uncertainty in prices of sawlogs towards 2025 (5–95% interval of -/+ 60% relative to the mean price). Similar magnitudes are found for sawnwood prices, while pulp and paper prices have somewhat lower price uncertainty according to the model simulations. Production and harvest level generally show greater variation than price, presumably due to the implemented elasticities in the model. Production level variation generally exceeds the harvest level variation because of added uncertainty from different products that does not affect the harvest variation directly.



Figure 4. Modelled mean, median, and 5% and 95% quantiles for prices and production levels for main forest products and roundwood assortments. Uncertainty in world market prices for the main forest products, and the exchange rate parameters (ALL). The y-axis is a ratio axis with the mean as the reference.

Table 3 displays the median uncertainty of the individual scenarios and shows indirectly the relative contribution of the uncertainty from the exchange rate (EXC), all product prices (PROD) and sawnwood prices (SAW) on the total uncertainty (ALL), respectively. The results show that uncertainty in the exchange rate has a relatively large impact on the modelled price and production variations. Production and sawnwood price uncertainties affect both price and production level to a considerable degree, since both the production of final products and world market sawnwood prices affect the pulpwood prices. As a result of being affected by more parameter uncertainties, the production level shows the highest variability. As in Figure 4, variation increases with compounding uncertainty, being 2–4 times higher in the 8th year compared to the 1st year.

**Scenario Final products Final products Roundwood**

**and roundwood**

 Price Production Price Production Price Harvest

1st year with uncertainty

ALL 6.1% 26% 4.1% 30% 7.9% 15%

EXC 3.1% 3.8% 3.1% 3.8% 3.5% 4.7%

PROD 0.5% 5.0% 0.5% 30% 2.0% 3.1%

SAW 5.5% 7.6% 0.8% 1.9% 7.5% 13%

8th year with uncertainty

ALL 23% 64% 12% 80% 26% 45%

EXC 10% 14% 10% 10% 10% 14%

PROD 3.2% 24% 3.2% 82% 7.4% 14%

SAW 20% 15% 3.1% 6.8% 23% 33%

Table 3. Calculated median uncertainty for the four scenarios for price, production and harvest, for all products and roundwood, for the main forest products, and for roundwood separately. The median is calculated with use of the representative relative uncertainty for products shown in Figure 4. (ALL – uncertainty in exchange rate and product prices, EXC – uncertainty in exchange rate, PROD – uncertainty in product prices and SAW – uncertainty in sawnwood prices)

Figure 5 displays simulated uncertainty intervals from 2017–2025 for the different forest products for the ALL scenario. The means approximate the deterministic model solution. As mentioned above, the variation increases annually with annual compounding of parameter uncertainty and as seen from the figure, the uncertainty intervals towards 2025 are large. It should be noted that the model is run without any option to divest in new capacity, and that closures of mills would also likely take place in the low-price scenarios.



Figure 5. Modelled mean, median, 5%, 10%, 90%, and 95% quantiles and max/min for prices of main forest products for the ALL scenario.

Similar to price variation, production variation increases with compounding parameter uncertainty (Figure 6). The median and mean production levels suggest a declining trend for Norwegian production, but the variability range shows that the future production levels are associated with great uncertainty. The production of all products ceases or is close to zero in the 5% quantiles.



Figure 6. Modelled mean, median, 5%, 10%, 90%, and 95% quantiles and max/min for production volumes of main forest products for the ALL scenario.

# Discussion

Even though the uncertainty in the underlying historical data material is easily available, only a few studies have used uncertainty simulations systematically in full-scale partial equilibrium forest sector models. This paper analyses the uncertainty and potential impact of some of the central parameters in the Norwegian forest sector. Norway has a small and open economy with an internationally oriented forest sector highly dependent on the world market. An important factor in this regard is the exchange rate, which directly influences the competitiveness of Norwegian producers. Over the last 10 years, the NOK/EUR exchange rate has varied widely (Norges Bank, 2017) (Figure 1). Uncertainties are calculated for the exchange rate as well as for world market prices of spruce and pine sawnwood, particleboard, fibreboard and newsprint. We have analysed the impact on the products mentioned, as well as on sawlogs and pulpwood from spruce and pine, because these roundwood assortments are the most prevalent in Norway.

One of the main assumptions applied in this study is that the year-to-year price variation is normally distributed (Figure 2). However, the real probability distribution may not be normally distributed. Figure 3 shows that historical variation for fibreboard and newsprint may not be normally distributed. Therefore, some of the highs and lows in Figure 2 may stem from increased or decreased shares of high or low-quality products sold in a specific year, or the fact that world market prices follow a more random distribution than assumed in this paper. Moreover, the historical prices are unit export prices, and exact quantities and prices for the products traded within Norway are not available. It is possible to test statistically which distributions explain the various uncertainties best. However, normally distributed prices are a fair simplification, which makes the Monte Carlo simulation more straightforward, although other distributions can be handled as shown in (Kallio, 2010).

We have assumed that no correlation exists between the different parameters included in the uncertainty analysis. This is a simplification, but as most of the product prices have rather low correlation (<0.50) (Table 2), the assumption does not imply significant errors. Indirect effects may adjust some of the correlation, such as price elasticities and change in timber supply.

The mean and median for the predicted values are not always equal (Figure 4). This implies that the probability distribution is a skewed normal distribution, which means that some result values are more likely, for example, for production of fibreboard in the uncertainties in the ALL scenario, where the median value is 0.33 of the mean value. It also appears that the deterministic reference value is higher or lower than the average values. Hence, a Monte Carlo approach is necessary to detect the most likely values under the assumed distribution of the input parameters (Table 1).

In this paper, change in world market prices is modelled as a vertical shift in the demand function, which leads to an increased or decreased demand for final products. This method for implementing the change in world market prices leads to observation of almost identical variation in the simulated consumption in product price scenario (PROD) and when both production prices and exchange rates are changed (ALL scenarios), while changes in exchange rates only (EXC) give little uncertainty in consumption. This shows that the uncertainty related to consumption, without the demand shift, is much lower than that related to price, production and harvest.

In the ALL scenario, the production and harvest levels have the highest observed uncertainty (Figure 4) since production is more exposed to what happens abroad than to changes in domestic prices. These results are consistent with Kallio (2010) and are particularly true for the exchange rate scenario, where producers are exposed to different production costs in Norway than abroad. This trend is strongest after the first year with uncertainties and does not have the same increase rate as production uncertainties. If the prices in Norway fall due to the price elasticities, demand will rise. The total production may therefore increase because of the added Norwegian demand, and this production may come from within Norway or abroad, depending where the lowest marginal cost occurs, as long as the marginal cost does not exceed the marginal revenue.

Kallio (2010) suggests that the exchange rate may radically change the supply and demand balance across regions. This is in line with our findings, which suggest that the exchange rate is the most important uncertainty factor in the first period, as it leads to a direct change in the competitiveness between foreign and domestic producers. For the domestic forest industry, uncertainties in world market price are the most important factor (Table 3). The overall uncertainty is highest in the ALL scenario, as both product prices and the exchange rate are assumed to be uncertain.

The implications of an extreme combination of changing world market prices and exchange rate can be very dramatic (Figure 5). The prices of sawnwood will in the most extreme scenarios either be close to zero or result in a three-fold price increase. The extreme scenarios are, however, outside of the 10th and 90th quantiles. The values between the quantiles may be plausible, since the values are less extreme than the variation observed over the last 25 years, at least for sawnwood and particleboard. The demand for newsprint has undergone a dramatic change historically with rapidly decreasing prices (Figure 2). These changes will make it difficult to predict plausible future prices of newsprint. The predicted prices (Figure 5) for newsprint are marginally decreasing from today’s level, and a future drop in newsprint prices is plausible given results in Figure 5. However, the predominant driver for the declining newsprint production and prices in the future is the declining demand. The approach applied in this study may not portray the future demand for newsprint accurately.

It is difficult to predict future production levels with the use of NTM, since the model is extremely sensitive with regard to price parameters resulting in changes in production capacities. Maximizing producer and consumer surplus annually is an unrealistic assumption, since in practice investors tend not to be that myopic. Therefore, our projections may well exaggerate the volume of capacity investments in the timeframe applied in this study. The largest changes in prices and quantities may also not be captured since the model is partial and assumes all other prices and quantities fixed. Technological advancements, shifts in trends or, for instance, the proliferation of forest-based biofuel production, which will affect pulpwood prices (Kallio et al., 2018; Mustapha et al., 2017a), may have a significant impact on the future trajectory of the Norwegian forest industries.

This study has modelled only short-term uncertainty impacts on the initial values as well as nine years ahead, with uncertainties related to the Norwegian forest sector based on historical figures. If the model is used for long-term projections, other uncertainties should be taken into consideration, such as long-term trends in prices, the impact of climate change on growing stock, GDP growth, production technology improvements and new emerging products. Other factors related to demand and supply parameters such as elasticities regarding prices, GDP and growing stock are associated with high uncertainty and are strong candidates for inclusion in future forest sector modelling studies.

To incorporate more risk factors, it may be beneficial to include other and more computing-effective techniques than those applied in this study, such as Latin hypercube sampling (McKay, 1992). When using a model, it is always important to have a good understanding of the uncertainties that are related to the model. It should be noted that historical variations are usually good proxies for determining uncertainties within a short time frame, but caution must always be exercised when trying to extrapolate historical uncertainty.

# Conclusions

This study has found that the analysed uncertainties in exchange rate and world market prices as derived from historical data have significant impacts on harvests and forest industry production levels in the Norwegian forest sector. The relative standard deviation of modelled harvest levels was 15–45%. The relative standard deviation of modelled industrial productions was 30–80%, with fibreboard production having the highest value.

The uncertainty of modelled price, harvest and production level increased with the number of periods modelled. Exchange rates showed a lower gradient of uncertainty increase after the first year compared to the uncertainty caused by variation in world market prices. The uncertainty regarding world market prices is important for the Norwegian forest sector.

The study illustrates that improved modelling of forest products demand should be of high priority in future forest sector modelling development.

Within a short time frame, historical variations usually provide good proxies for determining uncertainties, but caution must always be exercised when trying to extrapolate historical uncertainty. To incorporate more risk factors, it may be beneficial to include other and more computing-effective techniques in the future, such as Latin hypercube sampling.

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