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Accounting for uncertainty in a forest sector model using Monte Carlo simulation

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ABSTRACT

Large scale forest sector models tend to have thousands of parameters, of which many have values that are unknown or not known exactly. Despite the wide use of such models in the policy analyses, the impact of the overall uncertainty on the results and the distribution of the resulting variable values have not been considered. It would be important for the users of the results to know the robustness of the model outputs and conclusions made to variations in model inputs. This study attempts to systematically account for the uncertainties in forest sector model analysis. Monte Carlo simulation is applied to a spatial partial equilibrium model for the Finnish forest sector in order to examine how the uncertainty over the parametric data and output price developments affects the model projections. The focus is on the sawlog market and sawnwood production. As a policy example, the impacts of forest conservation set-asides are examined in the presence of these uncertainties. The uncertainty in the basic parametric data seems to have rather moderate impact on the results. Instead, the unpredictability of the world market prices for the forest industry products is an important source of variation among the model projections. Hence, any single model projection should be perceived to be strongly conditional to the assumptions made concerning the developments of world markets. The model projections for the relative impacts of forest conservation seem to be rather robust despite the uncertainties.

1. Introduction

Large scale forest sector models tend to have thousands of parameters of which many have values that are unknown or not known exactly and which thereby rely on expert estimates or are represented for instance by the means of the range of possible values. In addition to the uncertainty in data, there is uncertainty over the future changes in the operating environment, like for example, how the demand for the final products or the prices for the exogenous inputs develop. Nevertheless, the model analyses typically only consist of a base case projection to which scenarios with alternative developments of the exogenous factors or policy variables are compared (for instance, Li et al., 2008; Solberg et al., 2003; Trømborg et al., 2007). In addition, sensitivity analyses with some modified parameter values are often presented (for instance, Kallio et al., 2006). The impact of the overall uncertainty on the results and the distribution of the resulting variable values are typically not addressed.

This paper presents a first attempt to systematically account for the uncertainty in the forest sector model analysis. Applying Monte Carlo simulation into a spatial partial equilibrium model for the Finnish forest sector, tests are made concerning the sensitivity of the model projections to uncertainty in the parametric data and to uncertainty regarding the future. Regarding the latter aspect, the analysis focuses on the developments in the energy and output prices over time. This said, it is recognized that, strictly speaking, almost all the model parameters face uncertainty regarding their future values. For example, inputs of electricity or labour per tonne of pulp, harvesting costs, and forest growth rates are not only subject to the errors in observing their correct values of today, but they also depend on factors that could be considered to be scenario assumptions regarding, for example, technical change. An additional source of uncertainty is created by the discrete factors including political decisions. The impacts of such factors are typically in the focus of the analyses. An actual example of the discrete and yet unknown factor affecting the forest sector is the planned increase in the Russian timber exports taxes, recently analysed by Honkatukia et al. (2008), Turner et al. (2008) and Solberg et al. (2009). In this study, it is assumed that high taxes on Russian roundwood exports are introduced in 2009. As a policy case, the impacts of forest conservation set-asides on the Finnish forest sector are examined.

The analysis uses a spatial partial equilibrium model of the Finnish forest sector, the SF-GTM (Ronnila, 1995), which was most recently updated in order to support the formation of the National Forest Programme with a provision of the development scenarios for the Finnish forest sector (Kallio, 2008). Other recent applications of the model include the studies on the potential impacts of old-growth forest conservation (Hänninen and Kallio, 2007) and the cost-minimizing location of the forest biodiversity conservation sites (Kallio et al., 2008).

Monte Carlo (MC) simulation is used to account for uncertainties in the data and assumptions. This means that random samples are taken from the assumed distributions of the uncertain parameters, and the

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model is solved for each set of such random parameter values. The procedure is repeated as many times as it is necessary for the changes in the sample means and variances to converge within the desired tolerances.

MC simulation is an effective means to address uncertainty in the complex models. Still, there are very few applications of it in the economic or sectoral models, and to our knowledge, no previous applications in the forest sector are documented in the literature. This may be due to computational costs of doing such analysis. Few applications in the economic modeling include for instance Abler et al. (1999) who employ MC simulation to account for parametric uncertainty in a computable general equilibrium model for Costa Rica. While the applications in the forest sector analyses are lacking, the method has been applied in some forest sector related studies concerning, for instance, the estimation of the effects of uncertainties in the forest carbon sinks and stock estimates (Peltoniemi et al., 2006, Monni et al., 2007), uncertainties in yield projections (Kangas 1998, 1999) and uncertainties in forest management planning (Kangas and Kangas, 1999). Kangas and Kangas (2004) provide a thorough review of the sources of uncertainty in the forestry related decision making, and their discussion applies well to the sector level economic analysis in this paper. For the taxonomies of uncertainties, the reader could also refer to Schultz (2008).

In the following, the SF-GTM model is described at the outset. Thereafter the data is presented and the sources of uncertainty in the data are discussed. The results are then presented starting from the base case where it is assumed that the Finnish timber imports from Russia will cease in 2009 due to planned high timber export tariffs, but that no other exogenous changes in the business environment will take place. The set of these base case projections called BAU focuses on the uncertainty related to the data on forest industry production costs, timber supply, and transportation costs. Random samples are taken from the assumed distributions of these data, and the model is solved to obtain projections for timber harvests and prices, and forest industry production. Thereafter, the uncertainty added with the assumption that the energy prices will increase randomly in the future (0%–3% per year). The set of scenarios with this additional source of uncertainty are referred to as ENE. Stochastic market prices for the forest industry products (set of projections called CYC) are then considered. Finally, attention is given to the change caused to the alternative developments in CYC due to the assumed forest biodiversity protection programme (PRO).

When presenting the results, emphasis is placed on the medium-term outlook of sawnwood production, and softwood sawlog prices and harvests. These timber grades have traditionally provided the most important source for stumpage income of the Finnish forest owners. In 2007, their share was close to 75%. Furthermore, their development influences the decisions on forest management. Hence, they are of great interest to the forest owners, sawnwood industry, and policy makers.

2. The forest sector model

The SF-GTM model integrates the growing forest resources, roundwood markets, the forest industry, and the demand for forest products. It simulates the behaviour of profit maximizing consumers, forest owners and the forest industry. Competitive equilibria for the markets are found by maximizing the sum of producers' and consumers' surpluses net of transportation costs, subject to the market clearance, and constraints limiting the production, consumption or trade (Samuelson, 1952). The supply of and demand for the forest sector products and the prices of wood and other intermediate products are determined endogenously. Because we consider only the forest industry located in Finland, we apply the small economy assumption implying that the real prices of the final forest industry products follow the world market prices and are given.

The model is static as it calculates the equilibrium for each year separately. When applicable, the data for parameters are updated after each year before solving for the market equilibrium for the next year, which brings in some dynamics to the model.

2.1. The model specification

Salo and Kallio (1987) and Ronnila (1995) describe how spatial, multi-agent, partial equilibrium for competitive markets can be found by employing mathematical programming. Because these earlier presentations largely encompass the model specification employed in this study, only brief description is presented here.

Fifteen regions i are included in the model, of which 14 represent Forestry Centers in Finland. The final region stands for the rest of the world, which consumes the forest industry products coming from Finland and which exports roundwood and chips to Finland. The endogenous sector commodities include 12 wood fibre categories including the forest industry residues (pine, spruce and birch sawlogs and pulpwood and chips, sawdust and bark) and 32 forest industry products (different types of mechanical forest industry products, pellets, pulp, paper and paperboard), some of which are not traded but used directly as an input in the specific mills (like PGW, TMP and NSSC pulps).

Let there be various separable activities $l(1,2,\ldots,m^i)$ for producing endogenous sector commodities $k(k=1,2,\ldots,n)$ in regions i. These activities correspond to the existing or new forest industry production lines and to the supply (harvests) of roundwood. Some activities simply provide conversion possibilities between substitute products, for instance from pine sawlogs to pine pulpwood. The known capacity extensions are modeled as activities entering at a certain period. The known mill closures and conversions from one product to another are accounted for. In addition, activities representing hypothetical new sawnwood and sulphate pulp mills (investment options) were defined in the data. Such capacity expansions are endogenous and subject to the profitability requirement that the investment and production costs must be covered at the market prices.

The production possibility set is limited by the capacities for activities l, for example capacities of the existing or potential (investments) production plants of the forest industry. In this study, the activity levels are fixed for the roundwood harvests in the state and company-owned forests and for the harvests in a foreign region exported to Finland. State and company fellings, which corresponded to roughly 20% of the total Finnish commercial removals in 2007, were assumed to gradually converge to their economically sustainable levels (Nuutinen and Hirvelä, 2006) by 2015. Russia is planning to raise taxes of timber imports to 50€/m^3 for all sawlogs and coniferous pulpwood by 2010 and on birch pulpwood in 2011. It is assumed that roundwood imports from Russia will cease following this schedule. A "business-as-usual" assumption is applied to the imports of sawmill chips and roundwood imports from other countries, with these imports assumed to remain at their estimated 2008 level. The choice to fix the levels for these activities was made due to lack of meaningful price elasticities for imports and the state and company fellings. The data suggest that the price elasticity of the state harvests is negative (Piiparinen, 2001), whereas the market prices in the company sales are typically defined *ex-post* according to the price statistics for the timber sales of private non-industrial forest owners. Harvesting activities of the private forest owners were limited so as not to exceed their region-specific economically sustainable harvest levels by more than 10% in any year.

Let $y^i=(y_l^i)$ be the vector of the production levels for activities l in region i, and let $\overline{K}_l^i$ be the upper bound (mill capacity, maximal harvest) and $\underline{K}_l^i$ the possible lower bound for activity l. Let $A^i=(a_{kl})$ be a $n\times m^i$ matrix of input–output coefficients of endogenous sector products k in activities l in region i. If k is the main product of the activity l, $a_{kl}=1$, if k is by-product, $a_{kl}\geq 0$, and if k is input, $a_{kl}\leq 0$. Furthermore, let $C_l^i(y_l)$ be the function of marginal costs in activity l that excludes the costs of endogenous sector (wood, pulp) inputs. For timber fellings of the private forest owners, $C_l^i(y_l)$ is defined as $c_k^i + \alpha_k^i y_l^{i\beta_k^i}$, where k refers to wood category obtained from this activity ($a_{kl}=1$), c_k^i is the non-stumpage part of the timber supply function, α_k^i is a scale parameter, and β_k^i is the inverse price elasticity for roundwood supply (The timber supply dynamics will be elaborated below). For forest industry production activities, $C_l^i = -\Sigma_f \pi_f^i a_{fl}$ where π_f^i is the unit price and a_{fl} is the input-coefficient of exogenous sector production factor f. Exogenous inputs f are disaggregated to electricity, heat, labour, waste paper, capital, and other variable costs.

Let $q^i = (q_k^i)$ be the endogenous vector of consumed quantities, and P_k^i the assumed, exogenously given real price for final product k in region i. In this application, foreign and domestic consumption for the final forest industry products are combined, because the Finnish forest industry is export-oriented with only small part of the production consumed at the domestic markets. The aggregate consumption was placed in the foreign region, while in the 14 domestic regions, P_k^i was set to zero for all k. Note that the domestic consumption of intermediate products, such as wood or pulp consumed in paper making, is taken into account inherently by the matrix A^i.

Finally, let D_{ijk} denote the transportation costs per unit of product k from region i to j and $e_{ij} = (e_{ijk})$ denote the vector of exports of commodities k from region i to j. The competitive market equilibrium can be solved for by maximizing the following NLP problem, where the objective function (1) presents the sum of consumers' and producers' surpluses net of transportation costs when all the markets clear, as it is required by the constraints (2). Endogenous prices for intermediary products (wood, chips, pulp) are obtained as shadow prices of constraints (2) in the optimal solution.

$$Max_{q^i, y^i, e_{ij}} \quad \sum_{ik} P_k^i q_k^i - \sum_{il} \int_o^{y_l^i} C_l^i(y_l) dy_l^i - \sum_{ijk} D_{ijk} e_{ijk} \tag{1}$$

s.t.

$$q^i - A^i y^i + \sum_j (e_{ij} - e_{ji}) = 0 \quad \forall i \tag{2}$$

$$\underline{K}_l^i \le y_l^i \le \overline{K}_l^i \quad \forall l, i \tag{3}$$

$$e_{ijk}, q_k^i, y_l^i \ge 0 \quad \forall i, j, k, l \tag{4}$$

The Eqs. (1)–(4) define a convex optimization problem. Therefore, any solution satisfying the Karush-Kuhn-Tucker conditions of the problem is optimal. The optimality conditions are equivalent to the conditions of competitive regional equilibrium, where shadow prices given by the material balance constraints (2) equal the respective market prices.

Solving the model above gives the solution for one data set and for one single period t. Before solving the next period $t+1$, the new periodic data is given for the model and functions are updated when relevant. For instance, prices π_f^i of exogenous sector inputs, or world market prices for the final products may be assumed to change in time. Also, the changes in the growing stock of timber shift the supply function, as discussed below.

2.1.1. Roundwood supply

In the first period, the stumpage price dependent part of the inverse timber supply function $\pi_k^i = \alpha_k^i y_l^{i\beta_k^i}$ is specified by substituting the observed base year quantities of timber sales, $\hat{h}_k^i$, timber prices, $\hat{\pi}_k^i$, and assumed inverse supply elasticities of roundwood, β_k^i in the Forestry Centers into this function and then solving the value of α_k^i from $\hat{\pi}_k^i = \alpha_k^i \hat{h}_k^{i\beta_k^i}$.

The changes in the productive growing stock, G_{kt}^i, caused by forest growth, wood harvests or forest conservation set-asides affect the wood supply tightness in a region through the shift parameter α_k^i. The base year growing stocks, G_{ko}^i are given as data. Thereafter, these volumes are updated in each period t employing the specification

$$G_{kt}^i = (1 + g_k^i) G_{k,t-1}^i - \sum_h a_{kh} y_{h,t-1}^i \tag{5}$$

where g_k^i is a growth rate of the growing stock, and $\Sigma_h a_{kh} y_{h,t-1}^i$ is the aggregated harvests obtained from the model solution in harvesting activities h. Assuming elasticity ε_k^i for timber supply, the supply shifter α_k^i may be specified in the terms of base year parameter values by equation

$$\alpha_{k,t}^i = \frac{\hat{\pi}_k^i}{((1 + \varepsilon_k^i((G_{kt}^i - G_{k0}^i)/G_{k0}^i))\hat{h}_k^i)^{\beta_k^i}}. \tag{6}$$

which enforces that the base year price is applicable to the updated reference supply.

2.2. Monte Carlo simulations and the data

Solving the model just once for years t, ($t=2009$, 2010,..., 2015) gives results for one data set and that would be done in a typical model analysis. In this study, four sets of MC simulations (BAU, ENE, CYC, PRO) are produced with different levels of uncertainties. Within each of them, the model is solved for 2009–2015 using several hundreds or thousands of data sets. To choose the number of data sets (projections) to be made, an heuristic rule was applied that allowed as many projections as necessary until the means of the variables of interest in year 2015 change less than 0.0% when the last new 300 projections were added to the sample. The variables considered for this heuristic rule were production of pulp, paper and sawnwood, and prices and harvests of pine, spruce and birch sawlogs and pulpwood in Finland.

The model requires a vast amount of data on the entire forest sector, and various sources of uncertainty are present in the data. Some data are subject to the errors related to the measurement and statistical sampling. Sometimes it is not possible to specify the exact single values for the parameters or the data is unknown. This is the case for instance with some missing data on the production technologies where data from a representative mill is used. Furthermore, the SF-GTM operates at the annual level, and thus requires aggregated annual data, while the source data often refers to monthly statistics. The data on reference prices and quantities are a typical example of this. While some uncertainties are statistical, some are of a stochastic nature. For instance, growing stock data is based on statistical measurement and as such subject to some error, whereas the growth of the stock is based on the assumption that it remains at its historical average level. However, the annual climatic conditions cause variations in the growth, and even the changes in the stand structure and forest management may propagate changes despite the short time period considered. Finally, the data reflect the fact that the model is only an overly simplified representation of the reality. For instance, there is no aim to model every possible paper grade produced by a certain paper machine, but rather the average or typical output of it. Similarly, all means for transportation and distances between all the mills and places of harvests are not specified, but the regional average distances are used.

The assumptions on the data made in the MC simulations are presented in Table 1. For additional and more detailed information on the data sources, the reader is referred to Kallio et al. (2008).

The model is specified and solved in The General Algebraic Modeling System (see http://www.gams.com) that supports random sampling from uniform, normal and log normal distributions.

Table 1
The assumptions on the data in the simulation sets BAU, ENE, CYC and PRO.

Data	Data source	Assumptions made
Growing stock, G^i_{k0}	10th National Forest Inventory (e.g., Korhonen et al., 2007)	Assumed lognormally distributed with standard deviation of 5%.
Growth rates for growing stock, g^i_k	Calculated from the data in 10th National Forest Inventory.	Assumed uniformly distributed varying 10% around the mean.
Stock elasticity of wood supply, ε^i_k	Leppänen et al. (2001) estimate for sawlogs (0.86).	Assumed lognormally distributed with standard deviations based on Leppänen et al. (2001).
Price elasticity of wood supply, $1/\beta^i_k$	Hänninen et al. (2006).	Assumed lognormally distributed with standard deviations based on Hänninen et al. (2006).
Cost of harvests, c^i_k	Finnish Statistical Yearbook of Forestry (2008)	Assumed uniformly distributed varying 5% around the mean.
Price of imported eucalyptus pulp, component in $C^i_l(y_l)$	The Finnish Board of Customs	In BAU and ENE, import unit values of the second quarter of 2008 in all periods. In CYC and PRO, this price follows that of hardwood sulphate pulp.
Energy prices, mainly components in $C^i_l(y_l)$	Energy statistics and own estimate due to lack of price data for large industrial consumers	In BAU, electricity price is 0.083€/kWh, fuel price is 7.3€/GJ. The biggest industrial companies assumed to get 25% discount from the electricity. In ENE, CYC and PRO, prices for energy including pellets and energy wood assumed to increase 0–3% p.a., the change drawn from uniform distribution each year.
Other production costs, components in $C^i_l(y_l)$	Several data sources. See Kallio et al. (2008).	Assumed uniformly distributed varying 10% around the base value.
Forest industry products prices, P^i_k	The Finnish Board of Customs. Monthly time series.	In BAU and ENE, export prices in the second quarter of 2008 assumed to prevail in 2009–2015. In CYC and PRO, prices are randomized using VEC model. See closer details in Section 3.3.
Export demand of sulphate pulp	Metinfo-database (the Finnish Board of Customs) for the reference values in 2007.	Demand of softwood and hardwood sulphate pulp in the Finnish owned mills abroad assumed to change ±2% (drawn from uniform distribution) annually and affect the reference value of pulp exports demand.
Transportation costs, D_{ijk}	Data from Metsäteho company combined with regional distance matrices	Assumed to follow uniform distribution varying 10% around the original data.

The assumptions are valid in all the simulation sets, except when mentioned otherwise.

3. Results

3.1. Projections with uncertainty in the basic parametric data (BAU)

It is not possible to project the future of an economic sector without making an assumption with respect to the operational environment. In fact, the "business-as-usual" assumption with little if any changes taking place can be strong. In the set of projections called BAU it was assumed that the roundwood imports from Russia end due to high tariffs coming in force in 2009, but no other changes in the operation environment of the Finnish forest sector were assumed to take place. The prices for the forest industry products and energy were assumed to stay in the level they were in the 2nd quarter of 2008. The variation in the results across the projections in BAU derive from the combination of uncertainties in the data related to timber supply (costs or harvesting, price and stock elasticities, initial growing stocks and its annual growth), the forest industry production costs, transportation costs, and the use of market pulp in the foreign mills of the Finnish companies. For these, the reader is referred to Table 1.

3.1.1. Results

The results of the BAU case summarize the projections for 2009–2015 based on 1400 data sets drawn randomly from the assumed distributions of the data. The sawnwood prices were assumed to remain at their early 2008 level. At this price level, the average sawnwood production decreases from over 12 million m^3 in 2007 to below 10 million m^3 in 2015, as seen in Fig. 1. The sawlog imports from Russia were assumed to stop, which could raise expectations for increased demand for domestic timber. Nevertheless, the sawmilling industry is reducing its production so much that there is no need for finding new sources to replace earlier imports from Russia. The domestic sawlog harvests decline. In 2015, the total harvests of pine and spruce sawlogs vary within the range 21–22.2 million m^3 (Fig. 2), which is clearly below the estimated economically sustainable harvests. The real prices of sawlogs also remain below their 2007 level during 2009–2015 (Fig. 3), but due to scarcer supply, they remain above the levels seen at the beginning of the decade.

The variation in the results across the projections is rather modest and it does not seem to grow along the time, although it would be possible that the impacts caused by data differences in the projections accumulated in time. The standard deviation of prices in 2015 is only about 0.4% (0.2€) for the pine and 0.7% (0.4€) for the spruce sawlog. For the harvests, the standard deviations of the projections were 0.8% and

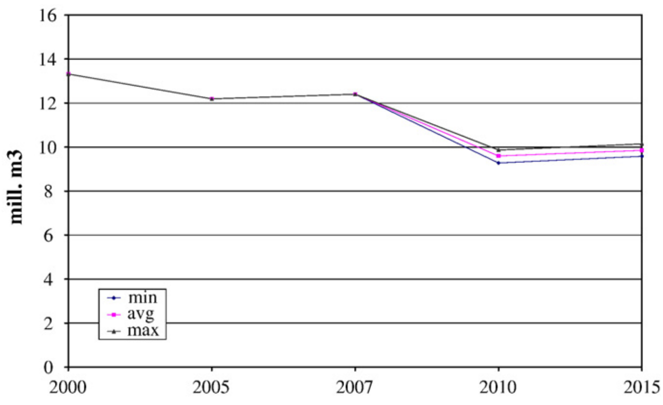

Fig. 1. Historic coniferous sawnwood production in Finland in the years 2000, 2005, and 2007 and the lowest (min), highest (max) and average (avg) production in 2010 and 2015 in the set of projections BAU.

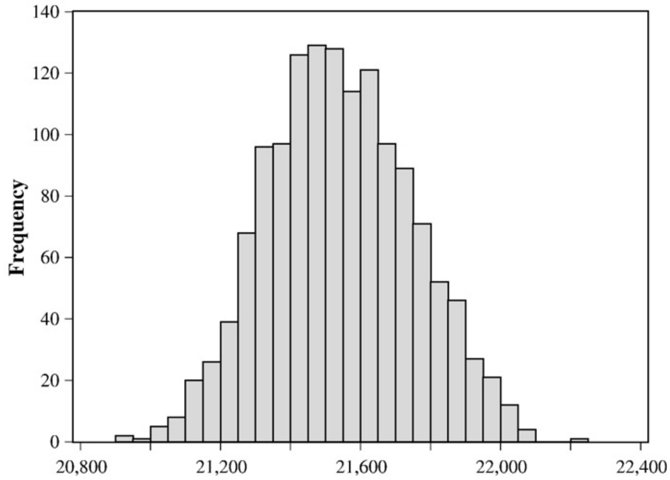

Fig. 2. Distribution of the coniferous sawlog harvests in 2015 in the set of projections BAU (mean 21.5 mill. m^3, median 21.5 mill. m^3, standard deviation 0.2 mill. m^3, $n = 1400$).

1.7%, respectively. Furthermore, the distributions for the sawnwood production, pine and spruce sawlog prices are rather symmetrically distributed around the mean, with the mean values being very close or equal to the medians. This is also the case with the total coniferous sawlog harvests in Fig. 2.

3.2. Projections with uncertainty appended with the random increases in the energy prices (ENE)

In the set of projections related to energy, ENE, energy prices (prices for fuels, electricity, pellets and wood fibre demanded for energy) are permitted to change by increasing them randomly between zero and three percent annually. All the other uncertainties introduced in the set BAU are also present. Sawnwood production is not very energy intensive, but the sector could also be affected indirectly by changes in sawmill chips prices, which could decrease due to the weakened competitiveness of the paper industry or, in the case of very weak pulpwood market, increase due to stronger potential to convert pulpwood and chips to bioenergy.

3.2.1. Results

The results can be summarized by simply noting that only very small changes in projections compared to those in the BAU-projections were observed in the sawnwood production and in the sawlog markets. In 2015, the average prices for spruce and pine sawlogs were marginally lower than in the BAU set. Adding this extra source of uncertainty to the

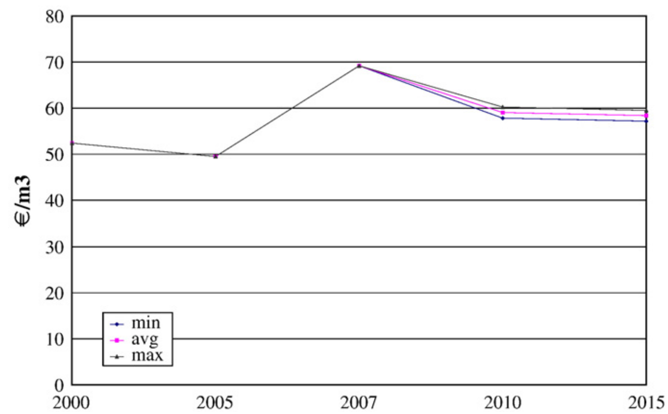

Fig. 3. Historic real prices of coniferous sawlogs in Finland in the years 2000, 2005, and 2007 and the lowest (min), highest (max) and average (avg) price in 2010 and 2015 in the set of projections BAU.

model even decreased the variance across of projections in the pine sawlog price and harvests. This is because the increasing energy prices simply narrowed the range of the profitable production choices for the forest industry. In 2015, the sawnwood production varied between 9.6 and 10.2 million m^3 across the simulations, with the average and median being 9.9 million m^3.

3.3. Projections with stochastic price developments for the forest industry products (CYC)

The prices of the forest industry products are highly cyclical, and great uncertainty prevails on how they develop in the future. In the simulation set CYC, the uncertainty in the sets BAU and ENE were extended by treating the market prices of forest industry products as stochastic parameters. Because the forest industry product prices were found to be co-integrated, the generation of the alternative price paths followed the method of Hilli et al. (2007). The approach is briefly described below.

A vector error-correction (VEC) model was initially estimated for the monthly real prices of 18 forest industry products based on the data (1989:8–2008:8) from the Metinfo database of the Finnish Forest Research Institute.

Let the $p_r = (p_{rt})$ denote the m vector of forest industry product prices in month r. These prices are assumed to satisfy a long-run equilibria $\beta_1 p_r = \beta_0$, with $\beta_0 \in R^d$ and $\beta_1 \in R^{d \times m}$, where d is the number of equilibria between the prices (in this application, $d = 2$). The deviation from the long-run equilibrium is $e_r = \beta_1 p_r - \beta_0$, and $e_r \in R^d$ is stationary, when the system tends to return to its long-run equilibrium.

The first differences of the variables p_r, $\Delta p = p_r - p_{r-1}$, have an error-correction form $\Delta_p = b_0 + b_1 \Delta p_{r-1} + \ldots + b_n \Delta p_{r-n} + \lambda\,(\beta_1 p_{r-1} - \beta_0) + \varepsilon_r$ where $b_O \in R^m$ is a vector or intercepts, and $b_1, \ldots, b_k \in R^{m \times n}$ define how the prices depend on the preceding prices in the short run, n is the number of lagged differences (in this application, $n = 4$), $\lambda \in R^{m \times d}$ defines responses to deviations from the long-run equilibrium, and $\varepsilon_r \in R^m$ is a vector of residuals with a multivariate normal distribution of zero mean.

The VEC model parameter estimates were used for generating alternative paths for future price developments up to 2015. In this, Cholesky factorization utilizing the covariances of the residuals ε_r was applied to generate random error terms in the equations for future price changes Δ_p (see Hilli et al., 2007). For some products moving clearly in pairs, such as pine and spruce sawnwood, or softwood and hardwood pulp, additional restrictions were set to ensure that their prices did not differ more than was historically acceptable. Finally, the annual prices for 2009–2015 used in the forest sector model simulations were calculated from the monthly prices. The prices for the few products left outside the VEC model were forecasted based on their observed correlations with the prices modeled. There is a declining trend in real prices of the forest products reflected in the VEC model parameters. To avoid the prices going unrealistically low or, in a few cases, unrealistically high, based on the values observed in the time series data, they were limited not to go more than 5% below the lowest monthly price observation during 2000–2008, or above the highest price observation in the same period.

3.3.1. Results

To follow the earlier discussed iteration rule, 2900 simulations were made. There were no dramatic changes in the results even after just a few hundred projections.

The VEC model generates the sets of stochastic price projections for the final forest industry products, where variance across the projections increases along the time. Naturally, this shows in the forest sector model simulations. In 2015, the sawnwood production, sawlog harvests and sawlog prices show large departures from their mean values, as seen in Fig. 4 showing the coniferous sawlog harvests, and in Figs. 5 and 6

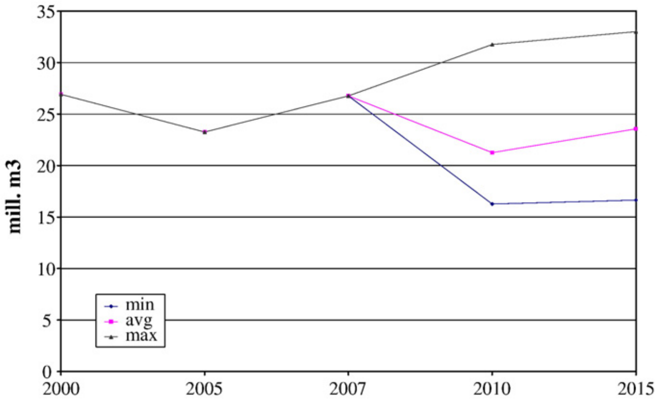

Fig. 4. Historic softwood sawlog harvests in the years 2000, 2005 and 2007, and the lowest (min), average (avg) and highest (max) harvests in 2010 and 2015 in the set of projections CYC.

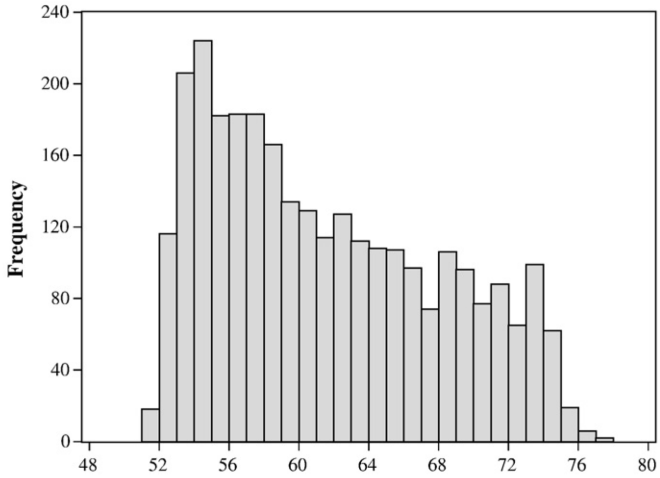

Fig. 6. Distribution of softwood sawlog prices (€/m^3) in 2015 in the set of projections CYC (mean 62€/m^3, median 60€/m^3, standard deviation 6.5€/m^3, $n = 2900$).

showing the distribution of sawnwood production and sawlog prices, respectively.

The mean sawnwood production is 10.7 million m^3 in 2015, and it seldom goes below 8 million m^3. At its highest, it approaches 14.9 million m^3. The standard deviation of the results is high, almost 1.8 millions m^3 (16%) in 2015. Because the declining real price projections in the data outweigh the increasing ones, the distribution of the sawnwood output projections is skewed downward, suggesting that it is less likely that the production climbs back to its historic higher levels. The sawnwood production reaches or exceeds the 2007 level only in about 20% of the simulated cases (Fig. 5).

As the sawnwood production is the main and almost only end use for pine and spruce sawlogs in Finland, with a minor proportion of spruce sawlogs being processed to plywood, the decline in sawnwood production directly affects the sawlog harvests (Fig. 4) and prices (Fig. 6). The real prices of pine and spruce sawlogs tend to go down, but there is a large spread between the minimum and maximum prices, with standard deviation being as high as 6.5€/m^3 (11%) for pine and 7€/m^3 (11%) for spruce. This reflects the large variance in the projected sawnwood production and in the sawnwood price projections behind them. Fig. 6 shows the distribution for the aggregated sawlog price. The observed variation in the sawlog prices has also been notable in the current decade as can be seen in Fig. 3. The simulations suggest an 80% probability that the price of sawlogs will be lower in 2015 than in 2007.

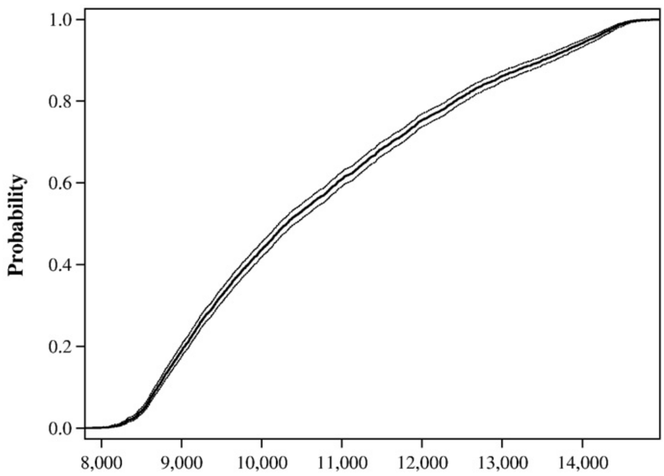

Fig. 5. Cumulative probability distribution of sawnwood production (1000 m^3) in 2015 in the set of projections CYC ($n = 2900$).

The results show that depending on the assumption made on the output prices, practically anything can happen, which clearly diminishes the potential to use the model for forecasting. Nevertheless, the analyst has typically some prior expectations on the price path. Such views can be accommodated in the analysis, but it should be emphasized that the results are highly conditional upon them. For instance, analysing the markets in early 2009, it seems that because the world's main economies have slid into recession, the most "pessimistic" price scenarios are even more likely. Accommodating this view, those events that suggested an improvement in price developments for forest industry products during the next couple of years could have been removed from the data sample. Also, even lower sawnwood prices could have been specified in the simulation set than those that seemed realistic based on the observations in the historic time series.

Recognising the large variance in the projections raises a question whether the model is robust enough to serve for policy analyses. In the next section, the impacts of conservation set-asides with respect to the set of projection in CYC are compared.

3.4. Policy analysis: impacts of forest biodiversity conservation (PRO)

As seen above, the world market price developments have an enormous impact both on the sawlog market and sawnwood production in Finland. Hence, if any single model projection were to be considered as a "forecast" concerning what will happen in the Finnish forest sector, such a projection should be considered highly dependent on the assumptions made on the world markets. This raises a question whether the model can give valuable information for policy analyses under such circumstances. This question is explored by looking at the impacts of a forest conservation scheme drafted by the preparation group of METSO II and analysed earlier with the SF-GTM model to respond to the information needs of the group upon the economic impacts of forest biodiversity conservation (Pohjola et al., 2007). METSO II (2008–2015) is a forest biodiversity programme for Southern Finland established in 2008. In the scheme considered here, 65 M€/year are spent in forest biodiversity protection during 2008–2015, so that annually about 23 000 ha consisting primarily of mature forests are set aside for conservation in Southern Finland. This scheme was found to cause the highest impacts among those analysed in Pohjola et al. (2007).

To look at the potential magnitude of the economic impacts of conservation plan, the simulations in the set CYC are repeated with the assumption that the forests are set aside for conservation and comparing each two with matching data. In practise, that is most simple to do by initializing the random data sampling processes of the simulation blocks with the same seed numbers. Then each projection in

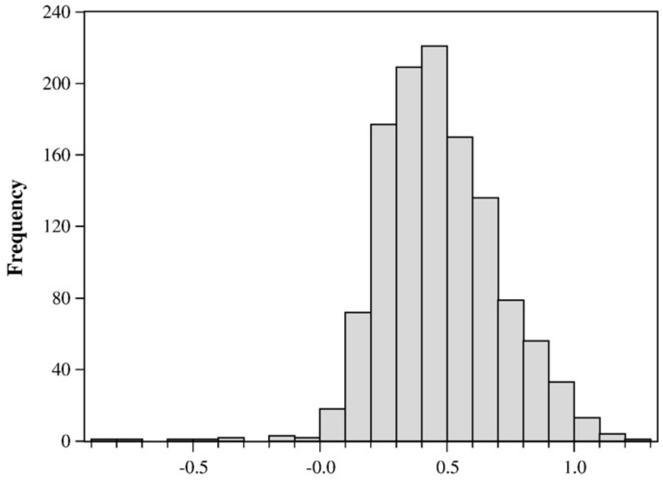

Fig. 7. Distribution of the changes (%) in softwood sawlog prices in 2015 in the set of projections PRO with respect to CYC (mean 0.42%, median 0.4%, standard deviation 0.23%, $n = 1200$).

set PRO has its own otherwise equivalent non-conservation counterpart, for which the results can be compared. The PRO set was calculated for the first 1200 CYC projections.

3.4.1. Results

As can be seen from Fig. 7, the forest conservation scheme increases the sawlog prices on the average 0.4%, because it reduces the stock available for harvests. This causes on the average 1% reduction in the sawnwood production (standard deviation 0.35) and, respectively, about 1% reduction in softwood sawlog harvests in 2015, compared to the equivalent cases without forest conservation. In Fig. 8, the decrease in sawnwood output from the corresponding base case in set CYC varies from about three percent to zero percent in 2015, but the production cuts more than 1.5% from the respective no-conservation case are really rare. Because sawlogs are mainly used in sawnwood production, changes in sawlog harvests parallel the sawnwood output in magnitude.

Despite the large variance in the projections defining the non-forest conservation reference cases, the variation in the impacts of the conservation scheme seem quite reasonable. Hence, the large uncertainty over what could actually happen in the output markets in the reference case without forest conservation does not markedly affect the impact analysis, and the results are therefore rather robust. Intuitively, this phenomenon could possibly apply to the other types of studies focusing on the impacts of a single event, but that should not be taken as granted.

4. Discussion

Despite the uncertainties regarding the data and the developments in the exogenous sectors, the earlier forest sector studies with partial equilibrium models have always applied deterministic models employing just one or few data sets. This paper has tried to explore the impacts of uncertainty in a forest sector model analysis in a systematic manner. Employing Monte Carlo simulation, random data sets were drawn from the assumed distributions of the parametric model data and of the assumed distributions of the future prices of energy and forest industry products. The results were calculated and reported with regard to three levels of uncertainties: (i) uncertainties in the model parameters only (BAU), (ii) BAU appended with uncertain energy price developments (ENE), and (iii) ENE appended with uncertainty in the cyclical forest industry product prices (CYC). In addition, the impacts of a forest biodiversity protection scheme (PRO) were examined. Sawlog markets were the main focus of attention together with the main industry affecting it, the sawmilling industry. It is of particular importance to get information on the developments in these markets, not only because the most part of the stumpage income of the forest owners comes from the sales of sawlogs, but also due to the fact that the developments in the sawlog market affect the forest management decisions.

Uncertainty analysis can help to determine which types of uncertainty would be most important to address (Kann and Weyant, 2000). In the present case, the parametric uncertainty alone resulted in relatively low deviation in the projections, whereas the stochastic output price developments broadened the distribution of the projected variable values considerably. It is also important to acknowledge that cycles in the market prices are likely to continue in the future. If the main aim of an analysis is to project future timber prices and harvests, the data on prices could naturally be shaped with the analyst's subjective assessment concerning the most plausible range of future prices. However, when presenting the results, it should be emphasized that they are highly conditional on that choice.

Although there is large variation in the results, they suggest that it is unlikely that sawnwood production will reach 2000–2007 levels in the next decade. Furthermore, despite the potential drop in the sawlog imports from Russia, sawlog harvests are unlikely to reach their earlier levels. This development would leave the coniferous sawlog harvests levels clearly below their economically sustainable level, which could have negative implications for forest management. Finding measures to improve the competitiveness of the industries processing sawlogs should therefore be given a greater priority in Finnish forest policy. One possible option would be to support R&D activities related to the use of wood as a construction material.

It is important for the policy makers and other users of the results to know the robustness of the results. In the simulations presented in this study, the variance of the projections was large when allowing for the output market cyclicality. Despite that, the variation of the impacts may be of more reasonable magnitude in single event or policy studies. When forest conservation is taken as a policy case, the range of relative impacts of conservation on the sawlog markets and sawnwood output across the simulations was of rather acceptable magnitude. The results were in line with those obtained in the earlier, deterministic studies for the similar conservation set-aside volumes. The additional feature of the approach chosen in this study is that it is able to produce the probability distributions of the results.

In the partial equilibrium models for the *global* forest sector, the world market prices for forest industry products are not exogenously given, as in the present small economy case, but endogenised to equilibrate the demand with the supply. Typically, such models are used without considering business cycles. Therefore, the volatility in the market price projections obtained as a result of such models is

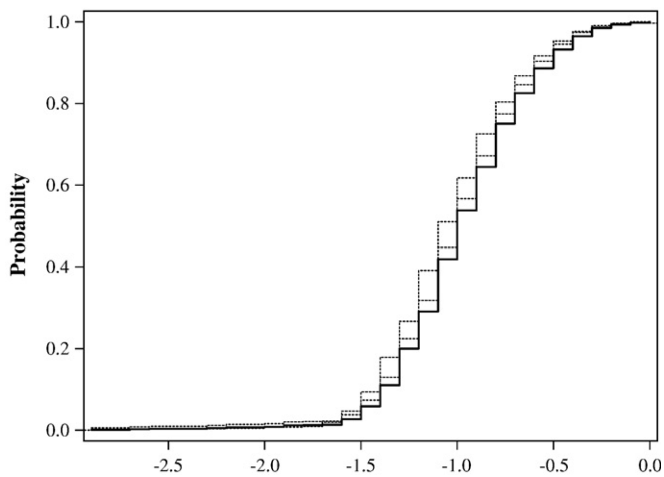

Fig. 8. Probability distribution of the change (%) in sawnwood output in 2015 in the set of projections PRO compared to CYC ($n = 1200$).

lower than that which was applied in this study. Nevertheless, there are factors both in the demand and supply side that are exposed to the uncertain developments in the exogenous sectors in the global models as well. For instance, the price and income elasticities of demand or other exogenous demand shifters used in such models are subject to large uncertainty. Furthermore, the demand and supply are apparently strongly affected by the unpredictable exchange rate movements, which may radically change the competitiveness across the regions in no time. So far, despite the frequent application of such models, no systematic analysis regarding the simultaneous uncertainties related to these factors in the global models has been made. The method presented in this paper proposes one possible way of exploring the impacts of such uncertainties in the future studies.

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