Impacts of agent information assumptions in forest sector modeling

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A B S T R A C T

The forest sector faces changing political paradigms and volatile policy measures. Policy makers rely on economic and biological models to inform them of the impacts and risks associated with both anticipated and unforeseen policies or shocks to the system. Assumptions about agents’ knowledge of future events are fundamental in all forms of models suggesting that the degree of information of future events may have large behavioral impacts. Despite the importance of this assumption, few studies have looked into what this difference in information may imply, and few studies have analyzed the importance of varying the degree of a priori information on the impacts of policy measures. This paper attempts to elucidate some of these impacts by comparing how an exogenous shock affects the Norwegian forest sector if the agents are assumed to have: (i) perfect information, (ii) information about the market shift only a limited time before its implementation or (iii) no a priori information. The shock analyzed is an import ban on all coniferous wood into Norway, which is possible if the Pinewood nematode (PWN) becomes more widespread in Europe. To examine this question, we adapt the Norwegian forest sector model NorFor to reflect perfect, limited and no prior information. The results indicate that if the agents anticipate the shock, they will begin to adjust harvest and production levels before it occurs. Due to high opportunity costs, harvest is reduced in the first periods to allow increases later. Bioenergy, with much lower profit than pulp and paper on the margin, is the hardest hit by the ban, while paper production is little affected. This may also be due to high capital costs in the paper.
industry and a perfectly elastic wood demand curve for bioenergy use. Substantial price increases for both raw materials and final products are suggested under either limited or perfect foresight. The analysis may provide useful insight about how agents react to sudden changes depending on their a priori information.

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Introduction

Forest sector models are widely used to analyze the impacts of changes in economic or policy frames, which may be gradual or occur as shocks. Depending on the assumptions about agent foresight in the models, such changes may imply different policy impacts. In a perfect foresight model, the agents are assumed to have perfect market information for the whole projection horizon. Thus, market shocks are actually not shocks in such models, as they are anticipated from the first period and the behavior is adapted accordingly. Examples of forest sector models assuming perfect information include the FASOM model (Adams et al., 1996), the various regional models of Oregon developed by Adams and Latta (2005, 2007), the Timber Supply Model (TSM) (Sedjo and Lyon, 1990) and models related to the TSM by Sohngen and Mendelsohn (1998) and Sohngen et al. (1999).

Yet, most models assuming that information available to the agents is imperfect are myopic models. These models assume that agents only possess information about the current period and the past, and know nothing about future conditions. The GTM (Global Trade Model) family, such as the GTM (Kallio et al., 1987), CGTM (Cardellichio et al., 1989), EFI-GTM (Kallio et al., 2004) and NTM (Trømborg and Solberg, 1995; Bolkesjø, 2004) as well as the Global Forest Products Model (GFPM) (Buongiorno et al., 2003) all operate under this assumption.

Questions have arisen over the degree to which perfect foresight models are fit to predict behavior since the underlying assumption of perfect information over the whole time horizon is extreme and rather far from observed behavior. On the other hand, it is also a simplification to assume that agents have no information beyond the current period. The questions should rather be how much information agents are assumed to have, and how different degrees of information impact behavior?

The purpose of the present study is to analyze behavioral impacts resulting from agents’ foresight conditions, i.e., no foresight, or foresight limited to some time, or full foresight, in a forest sector model. The study utilizes the Norwegian forest sector model NorFor, a dynamic equilibrium model with the default assumption of perfect foresight. The model is adapted to be able to reflect limited or no a priori knowledge of a future market shift.

We analyze the impacts of a general import ban on all coniferous timber to Norway beginning in 2020. Based on economic theory, several different forms of response are possible:

i. Having full information, agents will begin adapting from the first period of the simulation.
ii. If forest owners anticipate the ban, they will reduce timber harvest in the years before the ban in order to save timber for later periods when prices are higher.
iii. Due to (ii), harvests will increase more after the ban is introduced if the agents have perfect foresight than if they have not.
iv. If industry agents do not possess information about the ban, industrial production will be reduced considerably after the ban is imposed.

To test these hypotheses, four scenarios are run:

1. Base scenario with no ban (BASE).
2. Import ban in 2020 with perfect knowledge, i.e., the ban is known from 2010 (PK).
3. Import ban in 2020 with limited knowledge, i.e., the ban is known from 2015 (LK).
4. Import ban 2020 with no knowledge, i.e., the ban is known from 2020 (NK).
In scenarios 3 and 4, the model is solved iteratively over time periods with periods prior to knowledge of the import ban constrained to base scenario levels, reflecting the assumption that agents have no information of the ban and hence no basis on which to change behavior. From the period the import ban is known, the model is allowed to adjust. The differences in behavior among scenarios 2–4 reflect how the agents may adjust depending on whether they have information about the shock beforehand or not.

The introduction continues with a brief literature review of the underlying theory and its application, an overview of the Norwegian forest sector and the Pinewood nematode to provide further context for the study. The section “Methods” describes the NorFor model and how it incorporates forest investment decisions interrelated with industrial capacity, processing, and forest products trade. The results of the scenario analysis are presented in the third section and discussed in the section “Discussion and conclusions”, where also the main conclusions are drawn.

Foresight assumptions in economic modeling

The rational expectations hypothesis (REH), put forward by Muth (1961), asserts that the subjective expectations of the agents equal the expectations conditional on the information available. Or, by Muth’s (1961) own words (p. 316): “…that expectations of firms (or, more generally, the subjective probability distribution of outcomes) tend to be distributed, for the same information set, about the prediction of the theory (or the “objective” probability distributions of outcomes)”. The expectations may differ from the actual values due to unpredictable uncertainty. As Muth (1961) stated, “… nor does it [the hypothesis] state that predictions of entrepreneurs are perfect or that their expectations are all the same” (p. 317). He did not see the REH as the way agents make their expectations, but he considered more the hypothesis’ predictive power (Pesaran, 1987). The REH was based on two phenomena that averages of expectations in industry are more precise than models, and that “reported expectations generally underestimate the extent of changes that actually take place” (Muth, 1961, p. 316). However, the hypothesis has been subject to much debate, and there are even disagreements about what the hypothesis actually states (Gomes, 1982). Pesaran (1987) argues that this hypothesis is extreme and only holds within the frames of long-run steady state.

Contrary to the REH, the perfect foresight theory does not allow for uncertainty in the system. Perfect foresight corresponds to the REH without any uncertainty, and in this case, the expectations would equate the actual values (Sheffrin, 1996). Thus, the perfect foresight assumption is much stronger than the REH. Nevertheless, it is widely used in economic modeling.

Also in forest sector models, behavioral assumptions have been the subject of some debate. It has been claimed that the (global) market equilibrium in one period is “essentially independent of future market equilibria” (Dykstra and Kallio, 1987, p. 460). However, use of a perfect foresight model (where the opportunity costs of decisions in all other periods are considered in the harvest decisions in each period) may still give us useful information about how agents would act if they had perfect information. The basic theory of harvest behavior also indicates that future price expectations belong in the model, as owners determine harvest over time to maximize intertemporal utility. Depending upon the objective of the study and the type of impact to be studied, limited or perfect foresight could be assumed.

Despite the importance of future information on behavior and adaptations, few studies have dealt with this question in the forest sector. One exception is Sohngen and Sedjo (1996, 1998), who compared the price and inventory impacts resulting from several types of exogenous changes in a myopic and a perfect foresight model. This analysis has some limitations, however, since the model was extremely simple, involving only a timber demand curve, a simple age class-based forest inventory representation, and (in the myopic model) a timber supply curve. The sole source of dynamic adjustment in this analysis is the timber inventory. More complex models involving multiple market levels (beyond timber) may display different behaviors because of other dynamic elements, such as product inventories, capacity and capacity investment behavior. Fixed demand functions for timber that do not allow substitution adjustments over time may also have limited the analysis (Adams and Haynes., 2007). Finally, Sohngen and Sedjo did not consider changes in behavior that might occur in periods before exogenous
conditions shift. All changes occur in the “first” period of the analysis and there is no opportunity for anticipatory adjustment in the perfect foresight model.

Heide et al. (2004) applied the general equilibrium model MSG6 of the Norwegian economy to study behavior patterns of exogenous shifts depending on whether the shifts are of permanent or transitory nature, and whether the shifts are anticipated or not. There are twelve exogenous shifts in their study, ranging from changes in export and import prices (Norway is considered a price-taker in the world market) to productivity changes, taking place in the first year or year ten. Their results indicate that the degree to which a world market shift is anticipated or not influences the investment, consumption and leisure time behavior prior to the shift, and that anticipation of a shift reduces the disturbances in the market. Furthermore, the impact of the a priori knowledge assumption is the largest just after the market shift occurs and is dampened with time. Babiker et al. (2009) compared climate change mitigation costs in a myopic and perfect foresight version of the MIT Emissions Prediction and Policy Analysis (EPPA) model, a global CGE model. Without any abatement of greenhouse gas emissions, perfect foresight gives lower energy prices and hence higher consumption and emissions. An equal relative reduction in greenhouse gas emissions is more costly when the agents lack perfect information about the future, because future-looking agents can adjust production and consumption beforehand.

The Norwegian forest sector

The Norwegian forest sector constitutes a minor share of the GDP, 0.6% (SSB, 2010a), but is important for rural economies and employment. Recent annual harvest for sale fluctuates between 6 and 8 million m$^3$ (in addition to approximately 1–2 million m$^3$ outside official markets), which is well below half of the annual increment of approximately 25 million m$^3$ (Statistikkbanken, s.a.). The bulk of the productive Norwegian forest is owned by as many as 120,000 private landowners with the average property size being scarcely 60 ha (SSB, 2010b). Thus, almost all forest owners have their main income from outside the forest sector. The pulp and paper industry has consolidated over the last few decades, and consists of about 20 mills today. Newsprint, uncoated paper, and linerboard are the primary products with a large proportion of the output destined for export.

Approximately 40% of the pulpwood in the Norwegian forest economy is imported, of which 85% originates in Sweden and the remainder from other North European countries. In addition, between 700,000 and 1.1 million m$^3$ of chips are imported annually (Statistikkbanken, s.a.). Most of the mills consuming pulpwood and chips are situated in the eastern part of the country close to the Swedish border, and transport distance may be shorter for Swedish than for domestic wood. The sawlog import is limited to about 5% of the harvest. At the same time, pulpwood exports are about half of imports, while the sawlog exports are similar in magnitude to imports.

The Pinewood nematode in Europe

The North American Pinewood nematode (PWN), *Bursaphelenchus xylophilus*, is harmless to trees native to that continent, but kills Scots Pine *Pinus sylvestris*, the abundant pine species in Europe. Spruce is not killed by the PWN, but may be a host. PWN has caused great harm to pine in Asia, to where it was introduced (FCGC, 2008). North Europe has import restrictions on conifer timber and chips since the 1980s, when the PWN was discovered in pine chips loads imported from Canada and the U.S. Later, those restrictions were adopted by the EU and applied to most of Europe (Dwinell, 1997). Nevertheless, in 1999, the first proof of European PWN establishment was found in Portugal (Økland et al., 2010). Findings of PWN in wood pallets exported from Portugal to other European countries triggered measures, and the European Commission banned imports of all coniferous wood originating in Portugal which was not proved of going through specific heating treatment (European Union, 2008). The PWN is an important risk factor to European forests, and large amounts of money have been spent in an effort to control its spread. In Spain, where one single tree has proved infested, 3 million Euros were spent in 2010 for combat (EPPO, 2009). Import restrictions vary between European countries (EPPO, 2009). In Norway, an overall import ban of coniferous timber with bark from outside Europe and from Portugal has been in place since 2001. Measures such as bark removal and heat treatment are required depending on origin (LMD, 2000). Based on the fear in Europe of PWN spread and the

large pulpwood import into Norway, our hypothesis is that if the PWN is found in Sweden, it may have large impacts on the Norwegian wood market, due to the import ban which is likely to be imposed in such a situation.

Methods

NorFor is a spatial, partial equilibrium model of the Norwegian forest sector based on the assumption of perfect competition and perfect foresight. As such it is important to note that the model solution is intended to represent market potential and simulated policy changes shift projected market potential. Based on the objective function of the discounted value of the annual net social payoff, the model determines the optimal behavior of the agents in primary forest production and industry as well as consumers. A condensed mathematical description of the model is given in Appendix A.

The structure and data input of the forest industry portion of the model derives in large part from the NTMII (Bolkesjø, 2004), with updated capacity data. Forest growth depending on management is simulated with the stand simulator Gaya (Hoen and Eid, 1990). The incorporation of the forest management yields into the dynamic linear programming harvest schedule problem comes to a large extent from the regional models of Oregon (Adams and Latta, 2005, 2007).

NorFor includes 18 Norwegian counties (all counties except Finnmark) along with one foreign region for import and export and operates in five-year periods. The foreign region is a pure trade region with no industrial production and includes only the net trade with Norway.

The NorFor model can be divided into four parts: forest management and harvesting; industrial capacity and processing; wood products consumption and prices; and trade of timber and wood products.

Forest management and harvesting

The forest data are comprised of approximately 9000 national forest inventory plots covering all productive Norwegian forest land. The growth and yield for each plot is simulated with Gaya for up to seven management options in addition to final harvest: no management; thinning; precommercial thinning favoring hardwoods; precommercial thinning favoring hardwoods and thinning; precommercial thinning favoring softwoods; precommercial thinning favoring softwoods and thinning; and shelter wood harvest. The criteria for stand ages at which thinning occurs are set exogenously whereas timing of final harvest is endogenous. Yields are also generated for regenerated stands following final harvest and depend on site class, species, and regeneration methods. With the exception of shelter wood harvests, the conditions in a stand after final harvest are independent of the conditions of the prior.

In the dynamic optimization problem, the model selects the appropriate management options through time for each hectare of forest land. This management selection includes current stand harvest timings as well as regenerated stand silvicultural investment and harvest timings. Planting, site preparation as well as precommercial thinning options comprise the silviculture investments choices. The timber supply consists of sawlogs and pulpwood from thinning and final harvest of pine, spruce and birch species. Supply from abroad of wood and intermediate products is defined by a constant elasticity import supply function.

Industrial capacity and processing

The industry structure and data are to a large extent taken from the NTMII (Bolkesjø, 2004) but with updated capacity data for the pulp and paper industry. The solid wood industry is defined at the county level, while the pulp, paper and board industry is defined at mill level. Sawmills process the logs into lumber, and sell the slabs and off-cuts to the pulp, paper and board industries or for bioenergy. If no action is taken, capacity is depreciated at a fixed percent per year. Industry agents may also choose to maintain the capacity level or to add new capacity. Inputs other than wood and intermediate wood products, such as capital, labor, energy and recycled paper are priced exogenously.
The share of sawlogs and pulpwood in a stand is defined by Gaya, but sawlogs may be downgraded to pulpwood. Pulpwood can be used for producing pulp, paper and board, or downgraded as well for bioenergy purposes.

**Wood products consumption and prices**

The demand for final products is the engine for processing and harvesting. In all regions, demand functions for final products, such as sawnwood, paper grades and bioenergy, are represented by basic prices and quantities from NTMII runs and elasticities based on econometric studies. All products, raw material, intermediate and final products, can be exported, facing export demand functions similar to those for final products in Norway.

Bioenergy is a rather insignificant commodity in the large heating market, dominated in Norway by electricity. Thus, the energy demand is perfectly elastic at a fixed price, implying that bioenergy production does not impact the energy price.

**Trade of timber and wood products**

The forest sector is transport intensive, with long distances between the forest, forest industry and consumers. Wood and wood products can be transported between all regions in Norway and to/from abroad, and shipments will take place if the price difference is greater than the transport costs, to ensure the maximization of the net social payoff (Samuelson, 1952).

**Results**

The scenarios were run for 15 five-year periods, using a discount rate of 3%. To reduce the potential for the terminal valuation impacting the policy analysis, only two thirds of the modeling time horizon, i.e., from year 2010 to 2055, is presented.

**Base scenario: no ban**

In the base scenario, domestic harvest level is at 19.6 million m$^3$ the first period, decreasing until 2055, when 8.3 million m$^3$ is harvested. Almost half of the harvest (9 million m$^3$) in the first period is birch, but the relative contribution of birch declines rapidly, to about 10% of total harvest in 2055 (840,000 m$^3$). Harvested volume of coniferous sawlogs starts at 2.4 million m$^3$ increases to its maximum in 2020 (4.0 million m$^3$) and thereafter declines.

Timber imports increase steadily from about 3.6 million m$^3$ in first period to 4.3 million m$^3$ in end of the modeling horizon. 75% of the imports are coniferous pulpwood and 17% are birch pulpwood. Spruce is the only sawlog imported. Exports of timber amount to approximately 800,000 m$^3$, of which about half is pine pulpwood, and the remaining divided almost equally between spruce sawlogs and spruce pulpwood.

Prices for most final products increase over the time horizon. For spruce sawnwood, the most important solid wood product in terms of volume, the price growth is about 50% over the 10 period horizon, starting at $\sim 150\text{ NOK}$ (1,200 NOK).$^1$ The relative price increase of newsprint is similar in magnitude, starting at $523\text{ NOK}$, while uncoated paper sees a smaller increase of 13% from its first period price of $777\text{ NOK}$.

Demand for sawnwood increases from first to second period, and thereafter remains quite stable with spruce near 1.9 million m$^3$ and pine roughly 900,000 m$^3$. More than 75% of the pine sawnwood demand is met with imported wood; while the number for spruce sawnwood is 15–21%. Spruce sawnwood production follows the same basic pattern as demand. Newsprint demand experiences a small decrease to the second period, but is thereafter stable at 750,000 tonnes. Uncoated paper demand is 740,000 tonnes initially then increases stepwise to 800,000 tonnes. Bioenergy demand is volatile.

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$^1$ An exchange rate of 0.125 between Norwegian crones (NOK) and Euros has been applied throughout the paper.
Harvest of coniferous pulpwood (million m$^3$) in all scenarios.

Table 1
Harvest levels of coniferous and birch pulpwood relative to BASE.

<table>
<thead>
<tr>
<th>Period</th>
<th>Coniferous pulpwood and sawlogs</th>
<th>Birch pulpwood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PK (%)</td>
<td>LK (%)</td>
</tr>
<tr>
<td>2010</td>
<td>−5</td>
<td>−</td>
</tr>
<tr>
<td>2015</td>
<td>−6</td>
<td>4</td>
</tr>
<tr>
<td>2020</td>
<td>−5</td>
<td>2</td>
</tr>
<tr>
<td>2025</td>
<td>−9</td>
<td>−2</td>
</tr>
<tr>
<td>2030</td>
<td>−12</td>
<td>−7</td>
</tr>
<tr>
<td>2035</td>
<td>−12</td>
<td>−8</td>
</tr>
<tr>
<td>2040</td>
<td>−2</td>
<td>−1</td>
</tr>
<tr>
<td>2045</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2050</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>2055</td>
<td>9</td>
<td>−1</td>
</tr>
</tbody>
</table>

and the patterns follow the harvest levels. The first period demand is 20 TWh delivered heat in wood stoves, which is reduced to less than 5 TWh in the last period.

Forest management and harvest

Harvest levels of coniferous pulpwood for the four scenarios are given in Fig. 1. Some trends become apparent in analyzing the output. The PK scenario reduces its harvest levels immediately below the base and remains below until after 2040. The LK and NK both increase coniferous pulpwood harvest levels in the period agents gain knowledge of the import ban, however their harvest behavior is nearly identical following the 2020 period as harvests fall below the base case, yet remain above the PK scenarios until 2040.

Table 1 presents the percentage change from the base levels in total coniferous and birch pulpwood harvest for the scenarios. The coniferous total harvest numbers have the same basic traits as the coniferous pulpwood harvests discussed above. In the PK scenario, harvest is reduced prior to the ban, but the reduction continues, and increases in magnitude until 2040. The harvest patterns are similar, but of smaller magnitude, in the LK and NK scenarios. The birch pulpwood harvest behaves differently. Having knowledge from the first period, the agents reduce the harvest, but increase it substantially in periods after the ban is introduced, for reducing it even more later. Without any anticipation of the ban, birch pulpwood harvest is reduced by 22% in 2020. Birch sawlogs harvest is
very stable between the scenarios, starting at 43,000 m$^3$ in first period and increases to 82,000 m$^3$ in 2055.

Coniferous harvest is reduced to some degree in all ban scenarios in the first decades, but it levels off by 2040. When the ban is introduced in 2020 and not perfectly anticipated, the intertemporal allocation is smaller. Coniferous and birch pulpwood are substitutes in bioenergy (but not for pulp and paper), and harvest of birch stands increase considerably with the decrease in coniferous harvest which counterweights the coniferous decline. When coniferous harvest increases after 2040, harvest of birch goes down.

In the PK scenario, coniferous pulpwood is retained with between 0.5 and 1.5 million m$^3$, compared to BASE until 2035, and in 2050, pulpwood harvest is 0.85 million m$^3$ higher in the PK scenario than in BASE.

**Industrial capacity and processing**

In the model, pulpwood is used for pulp, paper, boards and bioenergy. The results indicate a shift in production with the ban. While pulp and paper production is relatively stable throughout the horizon, bioenergy declines rapidly (Table 2). Even if the ban is anticipated, production decrease accelerates only after the ban is imposed. Sawnwood production decreases to maximum 7–8% in the perfect knowledge scenarios, and up to 18% if anticipation is somewhat or completely limited.

**Wood products consumption and prices**

Wood prices would potentially be impacted by the ban. Results indicate that reducing the time agents know about the ban prior to its implementation may lead to greater price impacts (Table 3). Consequently, an import ban in 2020 has the largest impact when it is not anticipated. An import ban imposed in 2020 which is not anticipated beforehand or only five years beforehand may have large
impacts on product prices. Such a ban may cause the spruce sawnwood price to more than double over the horizon. The results suggest that a ban anticipated in ten years disturbs sawnwood prices less than the same ban with no prior information (Fig. 2). Similar patterns are found for newsprint (Fig. 3). The differences in prices between the scenario where the ban is known five years prior to the enforcement (LK) or not known beforehand at all (NK), are small. The degree of anticipation seems to have more impact on prices of pulpwood than on wood products.

Both sawnwood and paper consumptions are relatively stable in the years after introduction of the ban (Table 4), but sawnwood consumption is more disturbed than paper, and reduced a priori knowledge triggers larger impacts, also in later periods. Since bioenergy in the model is not tradable (only wood for energy), consumption equals production.
Table 4  
Consumption of coniferous sawnwood and paper relative to BASE.

<table>
<thead>
<tr>
<th>Period</th>
<th>Coniferous sawnwood</th>
<th>Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PK (%)</td>
<td>LK (%)</td>
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<tr>
<td>2010</td>
<td>−0</td>
<td>−</td>
</tr>
<tr>
<td>2015</td>
<td>−1</td>
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<tr>
<td>2020</td>
<td>−2</td>
<td>−3</td>
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<td>2025</td>
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<tr>
<td>2055</td>
<td>−3</td>
<td>−3</td>
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</tbody>
</table>

Table 5  
Import of wood products relative to BASE.

<table>
<thead>
<tr>
<th>Period</th>
<th>Pulp and paper</th>
<th>Coniferous sawnwood</th>
</tr>
</thead>
<tbody>
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<td></td>
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</tr>
<tr>
<td>2010</td>
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<tr>
<td>2015</td>
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<td>2055</td>
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<td>7</td>
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</tbody>
</table>

Trade of timber and wood products

Import of manufactured wood products (pulp, paper, boards and sawnwood) is not much changed with the ban. Only in the last periods of the time horizons do imports increase in the non-perfect knowledge scenarios (Table 5). Import of birch is not affected by the ban.

Export of coniferous timber is reduced by up to 10% in the PK scenario, and up to 21% in the LK and NK scenarios (Table 6). However, it is only in the latest periods that this reduction takes place. A 10% reduction corresponds to about 90,000 m³. Sawnwood export is only slightly impacted by the ban, while pulp and paper export is reduced to some extent.

Table 6  
Export of coniferous timber, coniferous sawnwood and pulp and paper relative to BASE.

<table>
<thead>
<tr>
<th>Period</th>
<th>Coniferous timber</th>
<th>Coniferous sawnwood</th>
<th>Pulp and paper</th>
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<td></td>
<td>PK (%)</td>
<td>LK (%)</td>
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<td>−21</td>
<td>−21</td>
</tr>
</tbody>
</table>
Discussion and conclusions

This study provides insight into how agents in the Norwegian forest sector could react to a sudden exogenous change depending upon their *a priori* information. Given that the model chosen for the analysis, NorFor, utilizes perfect information in its dynamic optimization of intertemporal welfare its resulting allocation of resources should be viewed as a sort of maximum market potential rather than a forecast. Scenario analysis using such a model provides decision makers with relevant information in the form of the change in market potential with the introduction of a policy. In general, perfect foresight smoothed out the impacts of shocks, since optimal decisions are made simultaneously for all periods. The constraint of limited foresight before the ban reduces the possibilities for intertemporal adjustment. In the model runs, the adaptations in the perfect knowledge scenario begin in the first period, by saving timber for later periods when its value increases. Similar results in the scenarios with LK and NK suggest that anticipating the ban five years beforehand does not give many chances for adaptations. The small differences between the results in the LK and NK scenarios compared to the PK case may also be caused by the fact that the investments in the first period in the LK case are done with incorrect assumptions about future market conditions, and the investments limit the possibilities of changes in the short run.

Comparing the model runs, the output levels of pulp and paper and sawnwood products change at most by $-9\%$ and $-18\%$, respectively, from the base case. In these instances there is little difference in the extent of response between the LK and NK cases, being 2–3 times the changes in the PK case. Similarly, consumption changes in the product markets are at most $-9\%$ for sawnwood and $-4\%$ for paper, and the pattern of larger but nearly equal changes in the LK and NK cases compared to the PK case is preserved.

In log markets, not much change is seen in the domestic harvest of sawlogs, which increases slightly with the ban due to less downgrading of sawlogs to pulpwood. Changes in pulpwood markets are larger than those observed in the product markets and more complex. Unlike the product market, the largest changes are seen for the PK case with smaller and roughly equal changes for the LK and NK cases. Stability in product markets is obtained at the expense of greater variation in the factor markets (a phenomenon commonly observed due to elasticity differences). The PK case with the smallest changes in product output and consumption (and trade) requires the largest shifts in the log market.

A large share of the pulpwood is used for bioenergy before the ban. Since bioenergy profit is considerably lower than for paper grades, bioenergy is the first to be phased out. The high capacity costs in the pulp and paper sector and the fixed price assumption for wood for bioenergy may also be factors in this result. Stability in pulp and paper production is attained at the expense of bioenergy. This is to some extent also true for sawn wood as well. Under PK, bioenergy production is reduced more and pulp, paper and sawn wood production is sustained correspondingly more than under LK and NK.

Patterns of change are roughly similar in log and product trade. Relative changes from the base case are smallest for products. Sawnwood imports show a larger relative increase than pulp and paper, and the sawnwood LK and NK import cases are nearly the same at about twice the PK case levels in the last periods. In exports, reductions in coniferous timber exports are only slightly larger for LK and NK than the PK case, while there is very little difference between the sawnwood and pulp and paper export cases.

The relative price impacts are not completely uniform but display pattern similar to those for production and consumption. Percentage changes in log prices are larger than those in the product markets. When the ban is implemented the spruce pulpwood price increases in the PK case are larger than in the NK case, which again are larger than those observed in the PK case. For products, the price impacts are very similar under LK and NK, substantially higher than under PK.

In the earlier Sohngen and Sedjo (1998) study, their scenario of sudden young timber dieback comes closest in wood supply effects to our import ban scenario – though they deal only with a timber market and their dieback occurs before the start of the simulations as a change in initial conditions. They find larger price impacts in the myopic model in the first years after the shift than in the perfect foresight model and that the prices in the two models converge with time. We also find larger initial changes in log prices under the LK and NK cases, but the log price projections diverge over time.
In the application of MSG6 (Heide et al., 2004) for exogenous market changes anticipated and unanticipated ten years in the future, the import price increase case is maybe the most comparable to our study. They found that consumers begin to adapt from the first period by reducing consumption and leisure. After the market shift has occurred, they reduce less if it is anticipated, and over the entire horizon, the anticipation leaves consumers better off, compared to the non-anticipation scenario. This is a general equilibrium model which has a totally different and more complex representation of consumption than NorFor, but we believe the results are of interest to compare.

To summarize the answers to the hypotheses posed in the introduction:

i. Having full information, agents will begin adapting from the first period of the simulation.

   We found clear evidence of adaptive behavior before the ban takes place, however the extent depended on the length of time ahead of the ban that the agents had knowledge. Knowledge five years ahead of time led to behavior similar to that of agents who received no a priori information of the ban.

ii. If forest owners anticipate the ban, they will reduce timber harvest in the years before the ban in order to save timber for later periods when prices are higher.

   This behavior is illustrated in Figs. 1 and 2. Forest owners continue to retain timber after the ban is imposed, as they foresee even greater price increases later.

iii. Due to (ii), harvests will increase more after the ban is introduced if the agents have perfect foresight than if they have not.

   Given Norwegian forests growth rates and the relatively short modeling time frame of this analysis, it may be difficult to determine if the harvest behavior noted in our results is consistent with this hypothesis. When the ban is perfectly foreseen, the agents do appear to retain more coniferous timber after the ban is imposed which would be consistent with a lengthening of rotations moving closer to the biological rotation thus leading to higher long term harvest levels. For birch, the trend is unclear.

iv. If industry agents do not possess information about the ban, industrial production will be reduced considerably after the ban is imposed.

   Post-ban production of pulp and paper and sawnwood does decline more in the LK and NK cases, as displayed in Table 2. For bioenergy, the production reductions are greater for the PK cases than for the LK and NK cases.

In considering our results, limited possibilities of substitution in the model may affect the simulation outcomes. A tree-level forest growth simulation model could to a greater extent optimize the species composition in harvest. In the present model, a stand or a part of a stand is harvested with all the species it contains. Pulp and paper industries may to some degree change the composition of input factors, particularly over time. However, due to technological development, this may be difficult to model for a longer period. Also, different species of sawnwood are probably substitutes in demand, even if not necessarily perfect substitutes.

The year of the introduced ban, 2020, is hypothetical and not based on projections of market changes. Choosing another year for the introduction of the ban might have impacted on the results, for instance might a more distant ban have caused larger differences between the scenarios.

The harvest levels reported here are substantially higher than recently observed levels, as the large growth increment gives flexibility to harvest increases and we have assumed a relatively high real term interest rate of 3% p.a. Forest owners may, however, have other, or additional, objectives than maximization of net present worth. Typically, forest owners prefer to pay for a more stable harvest level, or to even have non-declining yield. The additional harvest given here compared to the statistics, is to a large extent birch wood. Almost all birch, independently of quality, is used for bioenergy and is outside the demand for the traditional forest industry. This indicates that birch could be used to a much larger extent. However, it is important to keep in mind that the harvest levels given by the model are potentials of what might happen if all agents follow the behavior indicated by the objective function and constraints, and is therefore not necessarily comparable with historical data.

Interesting future research could be to compare NorFor with NTM, or to develop a myopic version of the NorFor model. It could also be possible to replace the forest management model with a simple...
growth model in NorFor to make the perfect foresight and myopic models more comparable. It would also be of interest to analyze the impacts of having a ban further into the future, to investigate further the importance of the time available for adaptation.

Conclusions

The impacts of the hypothetical import ban seem, according to the results, to depend upon the degree of information available about the shock before it occurs. Possessing this information before the shock may lead the agents to save more timber to later periods, when its value increases. Actually, the price increase over the whole horizon leads forest owners to save wood also after the ban is introduced. The PK results indicate that production in the industry may also be altered before the shock takes place. Because bioenergy production has relatively low profitability and a perfectly elastic demand for wood, pulp and paper production is conserved to the detriment of bioenergy. The prices of both raw materials and final products increase substantially, but more if there is no advanced information about the ban. In general, more information will smooth out shocks. More studies about the impacts and the consistency with the “real world” of the assumptions of foresight would be of great interest.

Appendix A. Model specifications

Objective function:
Maximize

$$
\sum_{t=1}^{T} \left[ \sum_{r} \sum_{fp} D_{r,fp}(Q_{r,fp,t}) + \sum_{p} D_{p}^{F}(Q_{p,t}^{FD}) - \sum_{p} c_{p}^{F}(Q_{p,t}^{FS}) - \sum_{r} \sum_{l} \sum_{cf} F_{r,cf}^{L} \times H_{r,l,cf,t} \\
- \sum_{r} \sum_{ip} \sum_{m} \sum_{f} E_{r,t,f}^{L} \times R_{ip,r,m,f} \times P_{ip,r,m,t}^{L} - \sum_{r} \sum_{ip} \sum_{m} I_{r,ip} \times (C_{k} \times C_{r,ip,m,t}) \\
+ C_{m} \times C_{M_{r,ip,m,t}} + C_{b} \times C_{B_{r,ip,m,t}} - \sum_{ar2} \sum_{p} T_{C_{ar,ar2,p}^{L}} \times T_{R_{ar,ar2,p,t}^{L}} \right] (1+i)^{-t}
$$

subject to:

$$\sum_{XM} \sum_{t} E_{pl,t,XM} = H_{Ap} \quad \forall \ pl$$  \hspace{1cm} (1)

$$\sum_{XM} E_{pl,t,XM} = \sum_{t2} \sum_{XM} \sum_{NM} NEW_{XN_{pl,t2,XM,NM}} \quad \forall \ t, pl$$  \hspace{1cm} (2)

$$\sum_{t2} \sum_{XM} \sum_{NM} NEW_{XN_{pl,t2,XM,NM}} + \sum_{t2} \sum_{NM} \sum_{NM2} NEW_{NN_{pl,t2,NM,NM2}}$$
$$= \sum_{t2} \sum_{NM} \sum_{NM2} NEW_{NN_{pl,t2,NM,NM2}} \quad \forall \ t, pl$$  \hspace{1cm} (3)

$$H_{r,cf,t} + Q_{r,cf,t}^{FS} + \sum_{ar2} T_{R_{ar,ar2,p,t}} + \sum_{m} P_{ip,r,m,t}^{FD} - W_{D_{p,r,t}} - \sum_{ar2} T_{R_{ar,ar2,p,t}}$$
$$- \sum_{m} R_{ip,r,m,p} \times P_{ip,r,m,t} - Q_{p,t}^{FD} = Q_{r,p,t} \quad \forall \ t, p, r$$  \hspace{1cm} (4)
\[
C_{ip,r,m,t-1}(1 - dr) + CM_{ip,r,m,t} + CB_{ip,r,m,t} = C_{ip,r,m,t} \quad \forall t, ip, r, m
\]

\[
CM_{r,ip,m,t} \leq C_{ip,r,m,t-1}(1 - dr) \quad \forall t, ip, r, m
\]

\[
PR_{ip,r,m,t} \leq C_{ip,r,m,t} \quad \forall t, ip, r, m
\]

\[
CB_{r,ip,m,t} \leq CMax_{r,ip,m} \quad \forall t, ip, r, m
\]

**Explanation of constraints**

(1): Allocation of existing forest
(2): Harvested existing stands go into a new management regime.
(3): Regenerated and re-regenerated stands go into a new management regime.
(4): Balance of wood inputs and outputs in industry.
(5)–(8): Capacity constraint.

**Definition of symbols**

**Sets**

\( ar, ar2: \) all regions, within and outside Norway.
\( cf: \) forestry cost factor, i.e., costs of logging (final harvest and thinning) and silviculture.
\( f: \) costs in industry of input with exogenously determined prices.
\( fp: \) end products, i.e., with a demand function in Norwegian regions.
\( ip: \) industrial product, i.e., intermediate and end products from industrial production.
\( l: \) log products, i.e., sawlogs and pulpwod of spruce, pine and birch.
\( NM, NM2: \) management regimes for forest land regenerated once (XN) or more (NN).
\( p: \) products, including log products, industrial products and end products.
\( r: \) regions within Norway.
\( t: \) periods.
\( T: \) last period.
\( XM: \) management regimes for existing forest lands, i.e., which have not been clearcut yet.

**Scalars**

\( Cb: \) costs to build new capacity as a share of IC.
\( Ck: \) costs of keeping capacity as a share of IC.
\( Cm: \) costs to maintain capacity as a share of IC.
\( dr: \) depreciation rate in industry.
\( i: \) interest rate.

**Parameters**

\( CMax_{r,ip,m}: \) maximum capacity for all periods.
\( FC_{r,cf}: \) forestry costs in region \( r \) and of cost factor \( cf \).
\( EC_{r,f,t}: \) exogenous costs in industry, in region \( r \), period \( t \) and of factor \( f \).
\( HA_{pl}: \) area in each forest plot.
\( IC_{r,ip}: \) investment costs in region \( r \) and for industrial product \( ip \).
\( R_{p,ip,m,f}: \) input ratio of factor \( f \) to production of industrial product \( ip \) and in technology \( m \).
\( TC_{ar,ar,p}: \) costs of transport a product from region \( ar \) to region \( ar2 \).

**Variables**

\( C_{r,ip,m,t}: \) capacity level in region \( r \), of industrial product \( ip \) and of machines \( m \).
\( CB_{r,ip,m,t}: \) new capacity in region \( r \), of industrial product \( ip \) and of machines \( m \).
$\Delta_i^{t} p_{r,m,t}$: maintained capacity in region $r$, of industrial product $ip$ and of machines $m$.

$D_{fp,t} (Q_{fp,t})$: area under the demand curve for end product $fp$ in region $r$ as a function of volume $Q_{fp,t}^r$.

$D_{p,t} (Q_{p,t})$: area under the demand curve for product $p$ in the foreign region as a function of volume $Q_{p,t}^{XM}$.

$E_{p,t}^{XM}$: area in plot $pl$ allocated to management regime $XM$ and harvested in period $t$.

$H_{ip,t} (c_{ip,t})$: harvest in region $r$, of log product $l$ with forestry cost factor $c_f$ in period $t$.

$lnv_{r,t}$: growing stock of log product $l$, in region $r$ in period $p$.

$N_{p,t}^{NM}$: area in plot $pl$ allocated to management regime $NM$, re-regenerated in period $t$ and harvested in period $t$ (after been through $XN$) $N_{p,t}^{NM}$.

$P_{ip,m,t}$: production of industrial product $ip$, in region $r$, in machines $m$ in period $t$.

$S_{p}^{f} (Q_{p,t})$: supply function for product $p$ in the foreign region as a function of volume $Q_{p,t}^{f}$.

$S_{p}^{s} (Q_{p,t})$: supply function for product $p$ in the foreign region as a function of volume $Q_{p,t}^{s}$ in the last period.

$Tr_{ar,ar,t}$: transport of product $p$ from region $ar$ to region $ar$ in period $t$.

$WD_{r,t}$: wood debris of product $p$, in region $r$ and in period $t$.

$NEW_{NM}$: area in plot $pl$ allocated to management regime $NM$, allocated to management regime $XM$ before harvest, harvested and regenarated in period $t$ and harvested in period $t$.

$NEW_{NM}$: area in plot $pl$ allocated to management regime $NM$, allocated to management regime $NM$ before harvest, harvested and regenarated in period $t$ and harvested in period $t$.

References


