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The global timber market: implications of changes in economic growth, timber supply, and technological trends

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Abstract

A partial equilibrium model was applied to the global forest sector in order to assess regional and global impacts of changes in economic growth, timber supply potentials, and technical trends. The model uses recursive price-endogenous linear programming and deals with eight geographical regions and 16 products. The base line projections of the model gave an average annual increase in global supply of industrial roundwood of 1.2% until the year 2010. The real price of sawlogs and sawnwood was found to remain approximately constant, whereas the prices of pulpwood and particles increased significantly during the first years, and then declined after the year 2000. The real prices of pulp and paper increased less than those of pulpwood and particles. The assumed variations in GDP growth rates had limited influence on quantities supplied and traded due to restricted timber supply potentials, but affected the real prices, especially of pulpwood and particles. Changes in the assumed timber supply potentials and technical change affected the real prices of pulpwood and particles significantly. Introduction of a price responsive timber supply also dampened the price peaks of pulpwood. Possible improvements of the methodology include empirical estimation of timber supply and of key parameters that determine capacity expansion, trade inertia, and technical changes.

Keywords: Forest sector; Global markets; Timber supply; Forest industries; Demand; Models

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1. Introduction

Differences in forest management, legal constraints on forestry, demand for forest industrial products, economic development and technological trends are factors that explain regional differences in the development of the forests. The availability and supply of roundwood will in turn influence both supply and demand of forest industrial products, as increased timber supply leads to decreased roundwood prices, lower costs for the forest industries and higher demand of forest industry products.

For long-term planning in both forestry and forest industries it is of considerable interest to develop long-term projections of demand, supply and prices under different scenarios. The main objectives of this study were to assess how changes in economic growth, timber supply potentials and elasticities and technological trends affect world market prices, regional and global demand and supply, and international trade of timber and forest industrial products. Results from such sensitivity analyses give valuable input for more detailed national forest sector studies, in particular regarding long-term world price trends. In this study, special attention was given to future world pulpwood prices and the price differences between sawlogs and pulpwood.

2. Methods

2.1. Modeling methodology

The development of economic models of the forest sector has been an important topic of research over the last 20 years. Forest sector models consist of supply/demand equation systems for forecasting and policy analysis. Examples of such sector models include national models like the SOS-model for the Norwegian forest sector by Randers (1977), the TAMM-model for the North American solid wood sector by Adams and Haynes (1980), the IBRD-forest model applied to Sweden by Nilsson (1981) and to Norway by Gundersen and Solberg (1984). Several international models have also been developed, such as the global newsprint market model of Buongiorno and Gilless (1984) and the comprehensive global trade model (GTM) developed at the International Institute for Applied System Analysis (Kallio et al. 1987).

The model built for this study is an adaptation of the global forest products model (GFPM) developed by Zhang et al. (1997) for the FAO outlook study for global forest products consumption, production and trade (FAO, 1997). The model structure is based on the Price Endogenous Linear Programming System (PELPSIII), proposed by Gilless and Buongiorno (1985) and improved progressively into the version of Zhang et al. (1993). The theoretical structure is that of spatial equilibrium in competitive markets. PELPSIII generalizes the problem specified by Samuelson (1952) to represent the production, transport, transformation, and consumption of several commodities. The market equilibrium in a particular year is found by maximizing the sum of producer and consumer surplus subject to material balance, capacity constraints, and possible trade barriers, in each region.

The dynamic changes from year-to-year are modeled by recursive programming, that is, the multiyear spatial equilibrium problem is broken up into a sequence of problems, one for each year. The theory combines market optimization in the short run and imperfect foresight of decision makers (Gilless and Buongiorno, 1987). From one period to the next, the demand changes in each region due to assumed changes in GDP. The potential wood supply changes according to a chosen scenario. Technology can also change, such as the amount of recycled fiber used in making paper and paperboard (Zhang et al., 1996). Production capacity increases or decreases according to new investments that depend on past production and the profitability of production in different regions, as given by the shadow price of capacity in the previous year. Then, a new equilibrium is computed subject to the new demand and supply conditions, new technology, new capacity, and inertia constraints that limit the change in exports and imports from year-to-year.

2.2. Main assumptions

The differences between the model applied in this study and the GFPM-model described in the FAO (1997) and Buongiorno et al. (1997) include the disaggregation of industrial roundwood into two groups: sawlogs, and pulpwood and particles, with attendant improvements of the representation of timber supply, and the division of the world into eight regions instead of individual countries. The disaggregation of roundwood was necessary to address the issue of future pulpwood and sawlog prices. The regional aggregation was meant to simplify the analysis, since global trends were sufficient for the present purpose. The regions are Africa, Latin America, USA, Canada, Asia, Scandinavia, the rest of Europe (Europe except Scandinavia and an area of former USSR) and the ex USSR (area of former USSR). Sixteen different products were recognized explicitly, with sufficient detail to represent the interaction between the paper and solid wood sub sectors. The products were defined according to the nomenclature given by the FAO (1996b). The year 1994 served as the base year and the projections were up to the year 2010.

The final demand for a commodity in a region was described by an equation that gave quantity demanded as a function of economic activity (measured by real GDP) and real commodity price. Each demand equation for the base year (1994) was defined by base year consumption, base year price and price elasticity. Base year consumption was either computed from production, import and export data (FAO, 1996), or in the case of the ex USSR, estimated as in the FAO (1997). Base year prices were the weighted averages of unit values of import and exports, in 1994 US dollars per unit. Transportation costs were not specified explicitly in this model, but the base-year import prices included transport costs. Price elasticities by product and region were those reported in the FAO (1997). GDPs were shifters of demand, and were strictly exogenous. Scenarios regarding GDP growth follow those used by the FAO (1997). The scenarios, summarized in Table 1, assumed that the GDP growth rates would tend to converge, but countries with higher current economic growth would continue to grow faster until 2010. Demand for primary and intermediate products derived from the demand for final products through input–output coefficients for each activity that described the technology in each region, such as in Takayama and Judge (1964). To each activity corresponded a manufacturing cost and a limited capacity of production. The supply of wood in each region was represented by the reservation price up to the wood supply potential, an exogenous variable. The price elasticity of wood supply was hence infinite up to the potential. The maximum potential roundwood supply up to 2010 for the base scenario, expressed as a growth rate from the base year production level, is shown in Table 1. This sets the maximum growth of wood supply. The actual supply could be less if conditions were such that it was worth

Table 1
GDP growth and growth in potential timber supply up to 2010

Region	GDP growth			Timber potential	
	1995	2000 base sc.	2010 base sc.	Annual growth to 2010 base scenario (%)	Annual growth to 2010 low timber pot. (%)
Africa	3.2	3.0	2.3	1.4	1.1
Latin Am.	1.1	3.1	2.3	1.3	1.1
USA	2.0	2.2	2.2	0.4	0
Canada	2.2	2.7	2.2	1.0	0.5
Asia	8.4	4.1	2.9	1.3	1.0
Europe	2.8	2.6	2.3	2.7	1.4
Scand.	3.7	2.2	2.6	0.8	0.4
ex USSR	−4.3	1.4	2.5	1.7	1.4

producing only part of the maximum potential. One improvement of this model relative to the GFPM was recognition of the possible use of residuals from sawnwood and veneer and plywood production as input in the production of wood pulp, particle board and fiber board. Waste paper supply is assumed to be price elastic and shifts in relation with the growth of GDP that reflects the increased waste paper available due to increased paper consumption. Waste paper supply is restricted by maximum recovery rates.

The manufacturing coefficients, defining the amounts of raw materials (sawlogs, pulpwood, various pulps, and recycled fibers) needed per unit of product (sawnwood, plywood, newsprint, etc.) were based on Kallio et al. (1987) and on the FAO (1997). The input coefficients were also adjusted to ensure consistency between input and output quantities by comparing consumption of raw materials and intermediate products with production of intermediate and final products in the base year. The technology was held constant at the 1994 level, except for paper and paperboard. There, as in the FAO (1997), it was assumed that the use of recycled paper and other fiber pulp would increase mainly as a substitute for chemical pulp.

Manufacturing costs by product and region, that is variable costs except cost of raw materials, were recognized explicitly in the model, and calculated as the difference between base year prices and cost of raw materials given by the base year prices and the input–output coefficients. Given the assumption of competitive markets, pure profits were nil, and the manufacturing costs included a normal return to capital.

Capacity changes were governed in this model by past production and by relative profitability. Capacity data were available for pulp and paper products only. For the base year the projected production capacities published in the FAO capacity survey (FAO, 1995) were used for pulp and paper products. For particle board and fiberboard, the base year capacities were set equal to the base year production, whereas for sawnwood and veneer and plywood, base year capacities were set equal to 1.2 times the base year production. A distributed-lag function links global capacity changes to changes in past global production. The global capacity change is then distributed by country, according to the shadow price of capacity in each country, and to the level of production (Zhang et al., 1993).

Imports and exports of sawlogs and pulpwood are no longer reported separately by the FAO. For the purpose of this study, it was assumed that the percentage distribution of net trade (exports − imports) of industrial roundwood between sawlogs, pulpwood and other industrial roundwood was the same in 1994 as in 1989. The model deals with total exports and total imports by commodity and region. Each region exports to the world market and exports from the world market. In each region, production plus imports equates domestic consumption plus exports. The adjustment of trade flows between countries or regions is bound to take time. Thus, trade inertia constraints were introduced to limit trade in a given year to be within a specified fraction of the previous year's trade (Buongiorno et al., 1997). In this model trade inertia constrained net trade from each region to the world market in a given year to be within 20% of that in the previous year.

3. Results

3.1. Base line projections

The base scenario represents a plausible development of economic growth, timber supply potential and technical change. Summary statistics on the production, trade and consumption of wood, pulp and forest industrial products are shown in Table 2. The base scenario gives an average annual increase in global supply of industrial roundwood of approximately 1.2% until the year 2010. The USA continues to be the largest supplier of industrial roundwood. Europe shows a faster increase than other regions in the supply of industrial roundwood, due to a high growth in potential timber supply. The timber potential is fully utilized for all regions, except for sawlogs in Europe from the year 2004 where 99% of the potential is

Table 2
Production (supply), trade and consumption, 1994 and base scenario projections[a]

	Product	Production				Net trade		Consumption		
		1994	2000	2010	1994–2010	1994	2010	1994	2010	1994–2010
A	Pulpwood	12 796	13 901	15 959	1.39%	1046	1257	11 750	14 702	1.41%
F	Sawlogs	24 127	26 210	30 090	1.39%	5169	13897	18 958	16 193	−0.98%
R	Particles	481	409	386	−1.37%	335	91	146	295	4.50%
I	Wood pulp for paper	1499	1801	1866	1.38%	227	841	1272	1025	−1.34%
C	Paper and paperboard	2497	3512	4694	4.02%	−1206	−324	3703	5018	1.92%
A	Sawnw. and ven.& plyw.	8999	7935	7640	−1.02%	−1087	−5296	10 086	12 936	1.57%
L	Pulpwood	47 552	51 445	58 653	1.32%	5328	352	42 224	58 301	2.04%
A	Sawlogs	72 365	78 289	89 259	1.32%	2451	8215	69 914	81 044	0.93%
T.	Particles	4913	5070	5714	0.95%	1078	1510	3835	4203	0.57%
	Wood pulp for paper	8845	10 558	12 619	2.25%	2779	2788	6066	9831	3.06%
A	Paper and paperboard	11 761	15 122	19 728	3.29%	−2316	−910	14 077	20 638	2.42%
M.	Sawnw. and ven.& plyw.	33 053	33 998	38 331	0.93%	1706	144	31 347	38 186	1.24%
U	Pulpwood	151 474	154 776	160 439	0.36%	−1874	−16 115	153 348	176 554	0.88%
S	Sawlogs	233 486	238 575	247 304	0.36%	14 181	555	219 305	246 750	0.74%
A	Particles	77 702	82 516	87 347	0.73%	6193	2784	71 509	84 563	1.05%
	Wood pulp for paper	58 531	61 071	66 770	0.83%	435	2615	58 096	64 155	0.62%
	Paper and paperboard	81 088	87 347	95 722	1.04%	−4443	2113	85 531	93 609	0.57%
	Sawnw. and ven.& plyw.	111 683	118 792	125 558	0.73%	−32 039	−39 419	143 722	164 977	0.87%
C	Pulpwood	35 700	37 986	42 127	1.04%	1874	8951	33 826	33 177	−0.12%
A	Sawlogs	142 028	151 124	167 598	1.04%	−4598	−9838	146 626	177 435	1.20%
N	Particles	50 104	53 779	60 677	1.20%	−457	−19	50 561	60 696	1.15%
A	Wood pulp for paper	24 703	26 179	25 470	0.19%	9889	10 427	14 814	15 043	0.10%
D	Paper and paperboard	18 358	19 597	21 197	0.90%	11 941	14 056	6417	7142	0.67%
A	Sawnw. and ven.& plyw.	63 985	68 691	77 437	1.20%	44 475	55 292	19 510	22 145	0.79%
A	Pulpwood	33 674	36 280	40 919	1.23%	−1568	−805	35 242	41 724	1.06%
S	Sawlogs	197 951	213 269	241 478	1.25%	−24 596	−42 368	222 547	283 846	1.53%
I	Particles	35 134	38 354	43 877	1.40%	−8838	−3616	43 972	47 493	0.48%
A	Wood pulp for paper	18 847	21 183	23 206	1.31%	−8305	−16 123	27 152	39 330	2.34%
	Paper and paperboard	75 901	100 600	123 077	3.07%	−8698	−25 881	84 599	148 958	3.60%
	Sawnw. and ven.& plyw.	130 385	144 270	166 204	1.53%	−11 660	−22 805	142 045	189 009	1.80%
E	Pulpwood	59 419	69 794	91 279	2.72%	−715	−1847	60 134	93 126	2.77%
U	Sawlogs	102 783	120 687	148 403	2.32%	−5000	−729	107 783	149 133	2.05%
R	Particles	25 216	29 478	34 956	2.06%	−899	−1021	26 115	35 977	2.02%
O	Wood pulp for paper	13 392	16 320	21 864	3.11%	−10 265	−7616	23 657	29 480	1.38%
P	Paper and paperboard	53 836	60 830	71 307	1.77%	−12 466	−6775	66 302	78 082	1.03%
E	Sawnw. and ven.& plyw.	60 001	70 762	82 636	2.02%	−25 288	−13 908	85 289	96 544	0.78%
S	Pulpwood	48 092	50 477	54 718	0.81%	−12 642	−12 540	60 734	67 258	0.64%
C	Sawlogs	55 674	58 435	63 345	0.81%	−570	−3191	56 244	66 535	1.06%
A	Particles	19 517	20 591	23 165	1.08%	−907	−130	20 424	23 294	0.83%
N	Wood pulp for paper	22 274	22 567	24 608	0.62%	4310	8116	17 964	16 492	−0.53%
D.	Paper and paperboard	22 340	18 590	22 411	0.02%	18 054	17 414	4286	4998	0.96%
	Sawnw. and ven.& plyw.	26 813	28 250	31 769	1.07%	17 924	21 658	8889	10 111	0.81%

Table 2 (*Continued*)

	Product	Production				Net trade		Consumption		
		1994	2000	2010	1994–2010	1994	2010	1994	2010	1994–2010
e	Pulpwood	35 423	39 216	46 463	1.71%	11 230	21 043	24 193	25 420	0.31%
x.	Sawlogs	93 234	103 218	122 291	1.71%	8138	33 320	85 096	88 970	0.28%
U	Particles	9409	8805	9790	0.25%	625	82	8784	9708	0.63%
S	Wood pulp for paper	4733	4177	4936	0.26%	930	183	3803	4753	1.40%
S	Paper and paperboard	5320	5344	7317	2.01%	1142	2319	4178	4998	1.13%
R	Sawnw. and ven.& plyw.	42 536	39 674	44 308	0.26%	8723	7087	33 813	37 221	0.60%
W	Pulpwood	424 130	453 875	510 556	1.17%					
O	Sawlogs	921 648	989 808	1 109 768	1.17%					
R	Particles	222 476	239 001	265 912	1.12%					
L	Wood pulp for paper	152 824	163 855	181 338	1.07%					
D	Paper and paperboard	271 101	310 941	365 455	1.88%					
	Sawnw. and ven.& plyw.	477 455	512 371	573 882	1.16%					

[a] Pulp and paper products are measured in 100 t, other products in 1000 m^3.

utilized, falling to 94% in 2010. The regional supply of pulpwood and sawlogs are shown in Figs. 1 and 2.

The USA's net export of pulpwood and particles decreases sharply and the USA becomes the largest importer by the year 2010 due to high economic growth combined with limited growth in the timber potential. Net exports of sawlogs from the USA decrease as well. The ex USSR continues to be the largest exporter of industrial roundwood, and the quantity is increasing, but stabilizes from the year 2006 onwards. Canada's net export of pulpwood and particles increases, whereas its net import of sawlogs increases similarly. Asia continues to be the largest importer of sawlogs and the quantity increases significantly, from 25 000 000 in 1994 to 42 000 000 in 2010. Scandinavia continues to be a large importer of both sawlogs and pulpwood, whereas imports by the rest of Europe decrease. Net exports of sawlogs

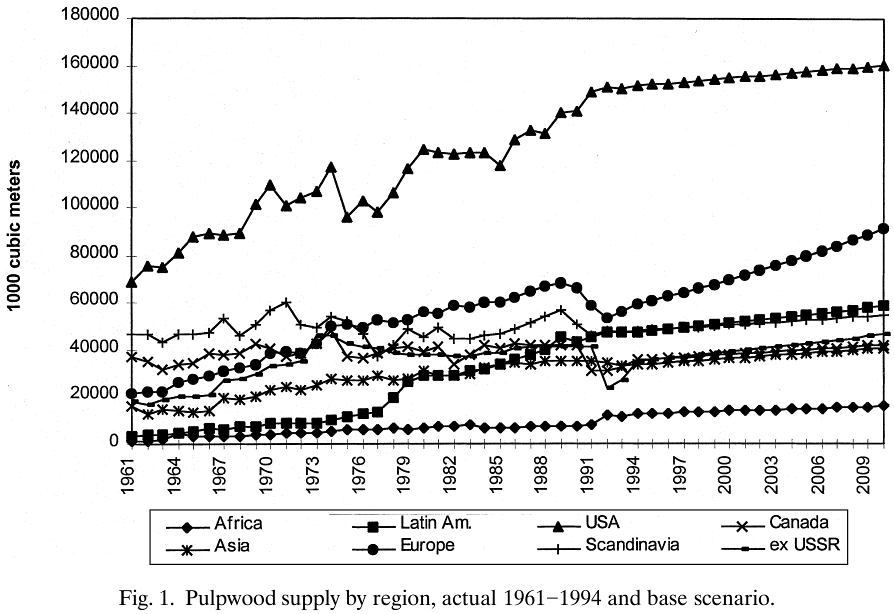

Fig. 1. Pulpwood supply by region, actual 1961–1994 and base scenario.

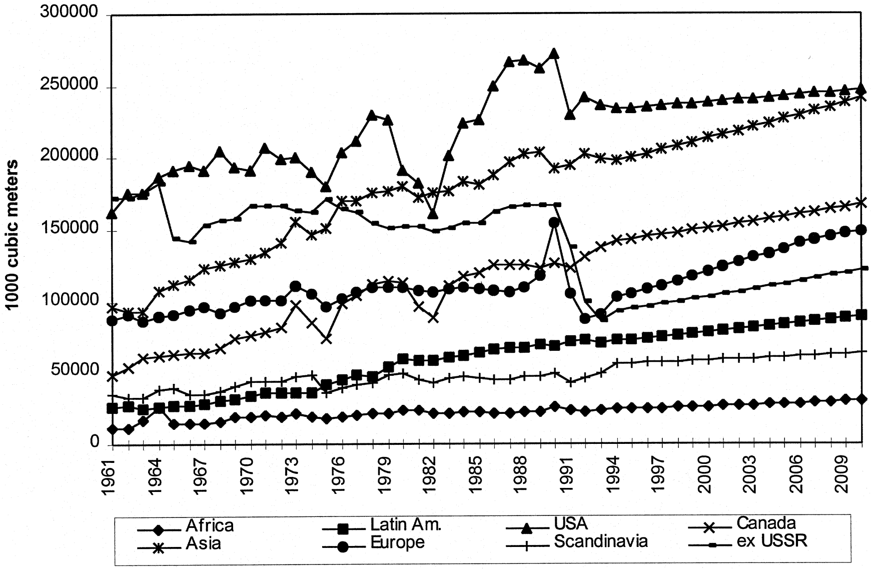

Fig. 2. Sawlogs supply, actual 1961–1994 and base scenario.

from Africa increase significantly. The USA continues to be the largest pulpwood consumer and Asia is the largest sawlogs consumer.

The real price of pulpwood is shown in Fig. 3. The peak in year 1998 is caused mainly by the assumed high demand in Asia. The price falls after the year 2004 as the economic growth is assumed to slow down. The particle price follows a similar pattern. As the capacity expansions in the pulp and paper industries react to past changes in production, the price peaks of pulpwood and particles, due to supply constraints, tend to lag the peaks of demand caused by strong economic growth. The low income elasticity for sawnwood and an excess sawlog supply potential in Europe cause the real sawlog price to be relatively stable (Fig. 4).

The assumed timber potentials are approxi-

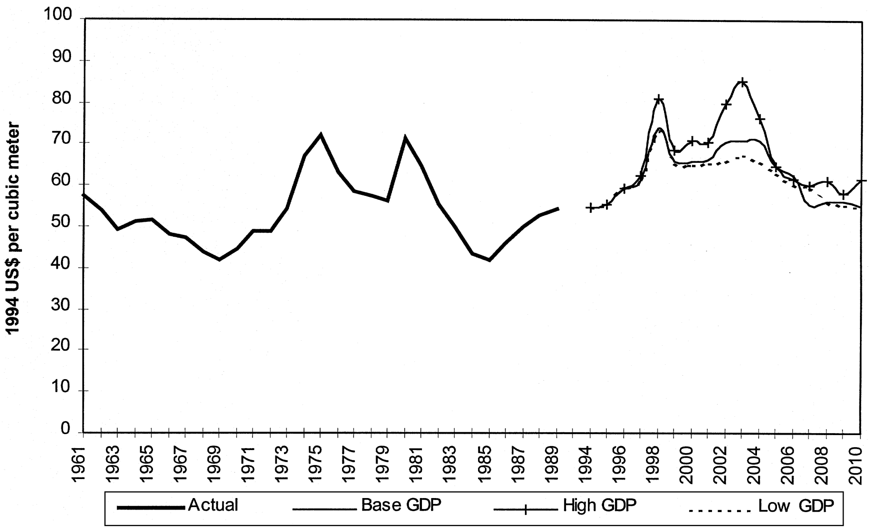

Fig. 3. Pulpwood price, by GDP scenario.

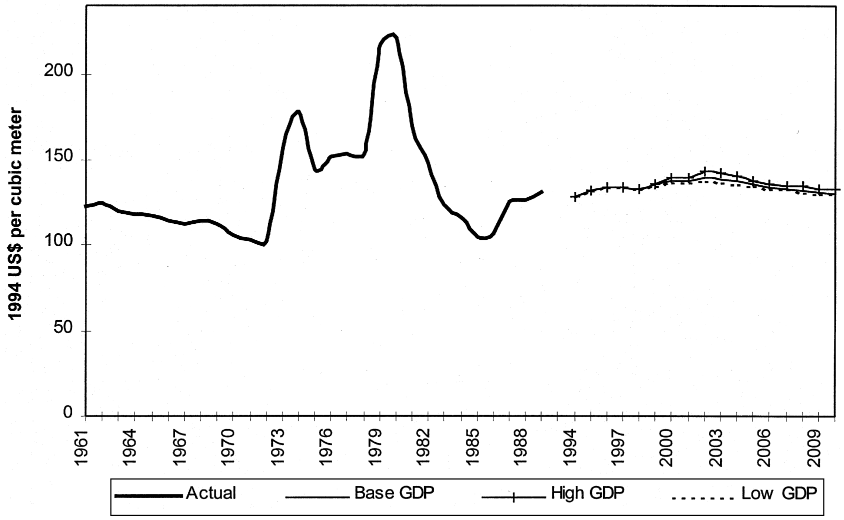

Fig. 4. Sawlogs price, by GDP scenario.

mately the same in this study and in the FAO (1997), and the model estimates for global industrial roundwood consumption are approximately equal. This is not surprising since several key assumptions were similar in general trends, if not in detail. There is only a small difference in the year 2010 where the FAO (1997) reports a global consumption of industrial roundwood of 1 780 000 000 m^3, whereas the total consumption in this study is 183 000 000 000 m^3. The average figure for the 10 studies reviewed by Brooks (1997) is 1 900 000 000 m^3.

The authors of FAO (1997) found that the real prices of industrial roundwood, sawnwood and wood-based panels would change little until the year 2010, and that the real prices of newsprint, printing and writing paper would decrease slightly under similar assumptions. The distinction between pulpwood and sawlogs introduced in this study shows that the development of real prices of pulpwood and sawlogs is significantly different. Within the products, the prices of sawnwood, veneer and plywood remains constant, whereas the prices of particle board and fiberboard increase somewhat until the year 2003, before they decrease and reach the 1994 level in 2010. The price of printing and writing paper increased steadily in this study, whereas the price of newsprint remained approximately constant due to excess production capacity. The price of other paper and paperboard fluctuated more, but its average real price changed little until 2010.

3.2. Sensitivity analysis

3.2.1. GDP growth

The effects of changes in GDP were analyzed by changing the GDP growth rates of the base scenario in two different scenarios, called 'high GDP' and 'low GDP', as specified in Table 1. The alternative growth rates were those used in FAO (1997).

The timber supply potential for pulpwood is almost binding in all three scenarios, i.e. nearly all the pulpwood available is used, so changes in GDP growth rates from the base scenario do not affect much of the global production level of pulpwood and particles. There is, however, a small decline in the global pulpwood supply in the low-GDP scenario. The changes in net trade and hence regional consumption of pulpwood and particles are relatively small for the different GDP growth rates. The prices of pulpwood are, however, sensitive to changes in the GDP growth rates (Fig. 3). The prices increase sharply under the high-GDP scenario, but there is less difference between scenarios in periods of falling prices as the sector is less constrained by the regional timber potentials.

The global supply of sawlogs and hence sawnwood and veneer and plywood are not affected significantly by the assumptions on GDP growth rates. There are only minor price differences for sawlogs between the high- and low-GDP scenarios (Fig. 4) due to low income elasticities for solid wood products.

3.2.2. *Timber supply constraints*

To analyze the consequences of assumptions regarding timber supply potentials, the growth rates of the base-scenario timber supply potential were reduced according to Table 1. The timber supply potential in the USA was assumed to remain constant at the 1994 production level, whereas the annual growth in timber potential was reduced by 20% in Africa, Asia, Latin America and the ex USSR, and by 50% in Canada, Europe and Scandinavia, compared to the base scenario.

The timber harvest in the ex USSR declined sharply after about 1990. To analyze the impacts of a possible faster recovery in timber supply from the ex USSR, the growth in the timber potential for sawlogs and pulpwood was progressively increased from 1.7% in 1995 as in the base scenario, to 5% in the years 2002–2005. From the year 2006 the growth rates were reduced steadily and approached 2% in 2010. This growth scenario was combined with less restricted trade of sawlogs, pulpwood and particles, by releasing the trade inertia constraints from 0.20 to 0.50 for those products as increased trade is an likely assumption for increased harvest in the ex USSR. The assumptions for the supply by the rest of the world stayed the same as in the base scenario.

The effects of the timber potential scenarios on the global pulpwood and sawlogs supply are shown in Figs. 5 and 6. The increased roundwood supply from the ex USSR in the high-USSR scenario does not affect the pulpwood supply from the other regions, but reduces sawlogs supply from Africa, Asia and Europe. In the low-potential scenario, net export of pulpwood and particles increases from Africa, Latin America and the ex USSR and imports by the USA and by Scandinavia increase. The high-USSR scenario combined with less restricted trade, increases net export of pulpwood and particles significantly for the ex USSR, and increases net imports by Europe and Scandinavia, whereas Canada's net exports decline from 9 000 000 to 4 400 000 m^3 in the year 2010. The consumption of pulpwood and

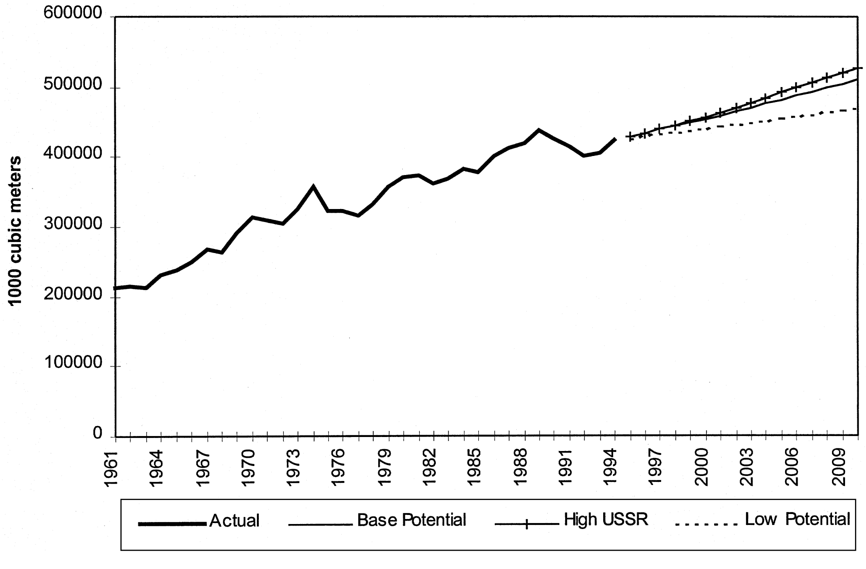

Fig. 5. Global pulpwood supply, by potential timber supply scenario.

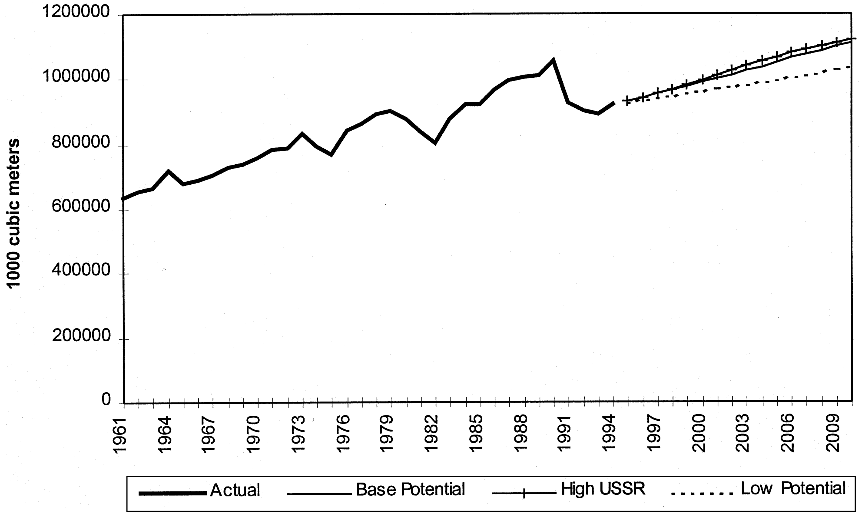

Fig. 6. Global sawlogs supply by potential timber supply scenario.

particles in the ex USSR does not change much despite the higher potential domestic supply, due to limited domestic production capacity in the forest industries and low demand for forest products tied with the low economic growth.

The increased supply and trade in the high-USSR scenario flattens out the price of pulpwood and sawlogs, whereas the prices increase much in the low potential scenario (Figs. 7 and 8). The prices of wood pulp and other manufactured products are affected significantly by these changes in wood prices. For example, the price of sawnwood is 25% higher in year 2010 in the low timber potential scenario than in the base scenario.

3.2.3. Price responsive timber supply

The results obtained with horizontal timber supplies, bounded by the timber supply potential, illustrates the shortcomings of this representa-

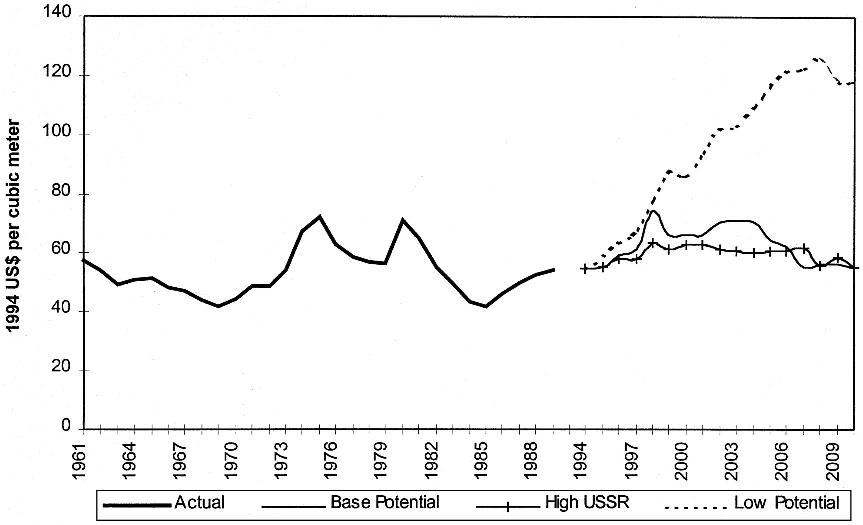

Fig. 7. Pulpwood price, by potential timber supply scenario.

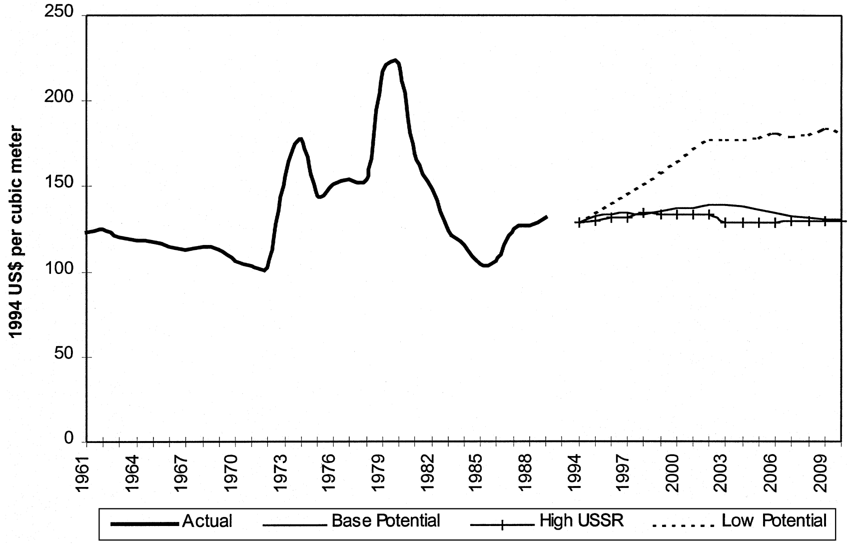

Fig. 8. Sawlogs price, by potential timber supply scenario.

tion, since prices remained unchanged until the bound was reached, and then climbed very fast without a corresponding supply response. To alleviate this, we experimented with price–elastic models of timber supply. There are very few estimates of international price elasticities of timber supply (Tomberlin, 1999). Here, we experimented with uniform price elasticities of 1.0 for sawlogs and 1.5 for pulpwood. These high elasticities were chosen to reflect the fact that the wood prices considered in the model are delivered prices (Cardellichio and Adams, 1990). In parallel with the introduction of a price elasticity of timber supply, the maximum timber potentials for the base year was increased to be the average of the 1994 production and the potential for the year

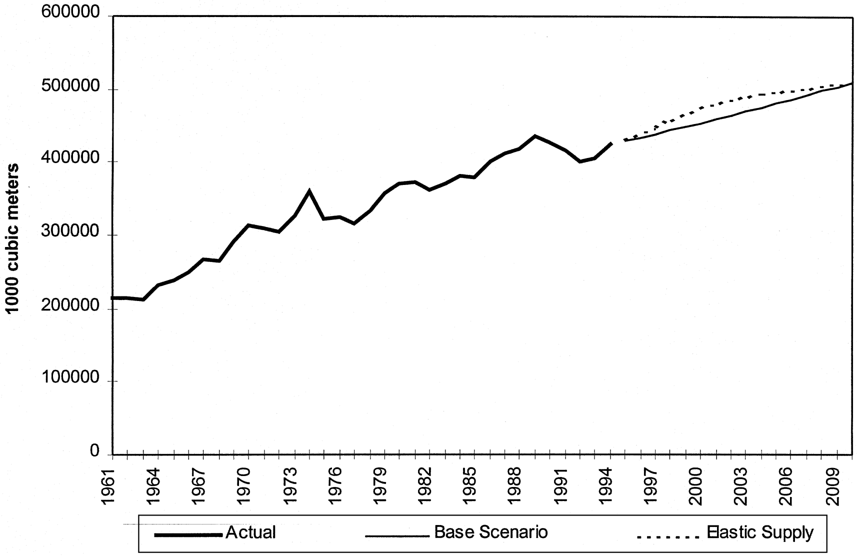

Fig. 9. Pulpwood supply, by price responsive timber supply.

2010 in the base scenario, and the growth rate implied that the timber potential in the year 2010 was the same in both scenarios. The effect of increased inventory on timber supply was also introduced by shifting the supply outwards at the same rate as the timber potential (that is the inventory shifts both the elastic part of the supply curve, as well as the maximum timber potential).

The effect of this 'elastic timber supply' scenario on the global supply of pulpwood is shown in Fig. 9. The timber supply is significantly higher in the elastic scenario in the middle of the projection period, but equals the base scenario supply as the economic growth slows down. Fig. 10 shows clearly that the assumed price elasticity of the wood supply is sufficient to eliminate the sharp price increase for pulpwood shown in the base scenario up to 2004. Instead, as the demand for sawlogs is modest, the effects of the 'elastic timber supply' on the price of log products is small. The sawlogs price remains at the 1994 level in the elastic supply scenario, while it increased slightly in the base scenario.

3.2.4. Technical change

To analyze the consequences of technical change, we looked specifically at the impact of changes in the use of recycled fibers in the production of papers. The 'high recycling' scenario assumed that use of recycled paper in paper production would increase beyond the increases already assumed in the base scenario. The 'low recycling' scenario assumed that the use of recycled paper would stay at 1994 levels. All other assumptions regarding timber supply and economic growth were as in the base scenario described above. The global consumption of waste paper by scenario is shown in Fig. 11.

In the low-recycling scenario, global production of pulpwood reaches the same level as in the base scenario, because the same timber supply potentials are binding in both scenarios. In the high recycling scenario, global pulpwood production is the same as in the base scenario up to the year 2004, but is then lower due to the substitution of recycled for virgin fiber. Average annual growth of pulpwood production from 1994 to 2010 is 1.2% in the base and low-recycling scenarios, compared to 0.95% in the high-waste scenario.

The trade of pulpwood and particles is significantly affected by the assumptions on technical change. In the high-recycling scenario, exports of pulpwood and particles increase significantly from South and Central America, but decrease from Canada. The USA continues to be a net exporter of pulpwood and particles in the high recycling

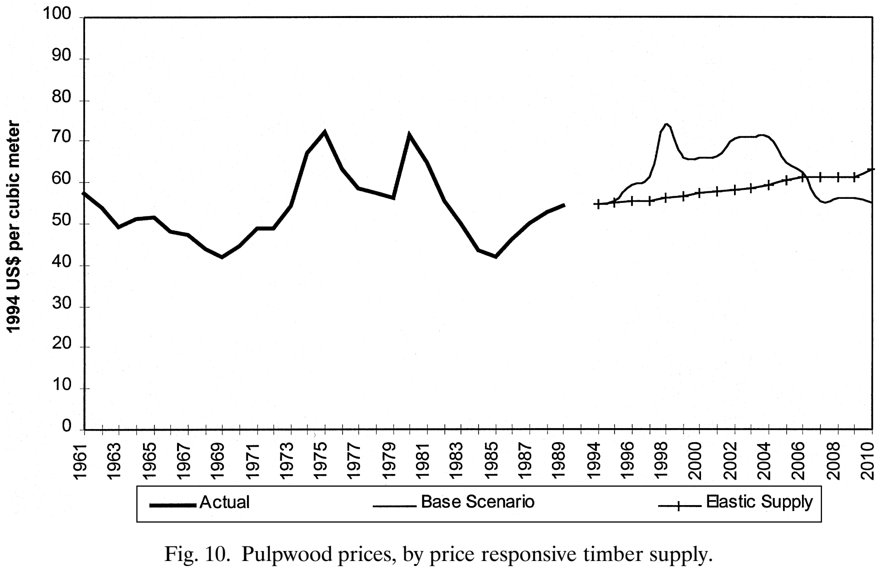

Fig. 10. Pulpwood prices, by price responsive timber supply.

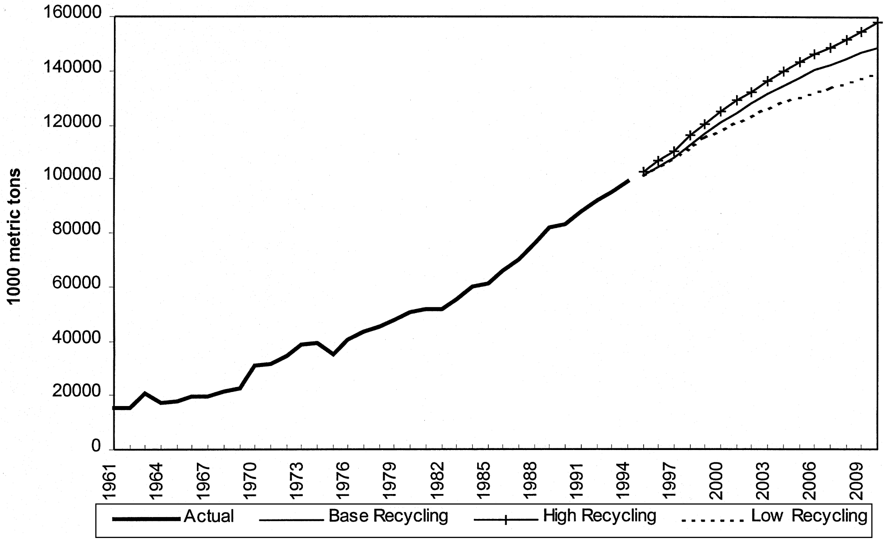

Fig. 11. Global waste paper supply, by recycling scenario.

scenario, whereas it becomes a significant net importer in the base scenario and in the low-recycling scenario. Scandinavia especially, but also Asia and Europe, increase their imports of pulpwood. The increased imports and consumption in Scandinavia are explained by the low price of pulpwood as the global demand decreases due to increased use of recycled paper. Scandinavia continues to use relatively high amounts of wood in paper production, even in the high-recycling scenario, hence the paper production and demand for pulpwood is sensitive to changes in the prices of pulpwood. The price of pulpwood is much higher if one assumes that recycling rates stay at the 1994 level. The high-recycling scenario, instead, maintains prices at their 1994 level until 2010 (Fig. 12).

Global production of paper and paperboard is

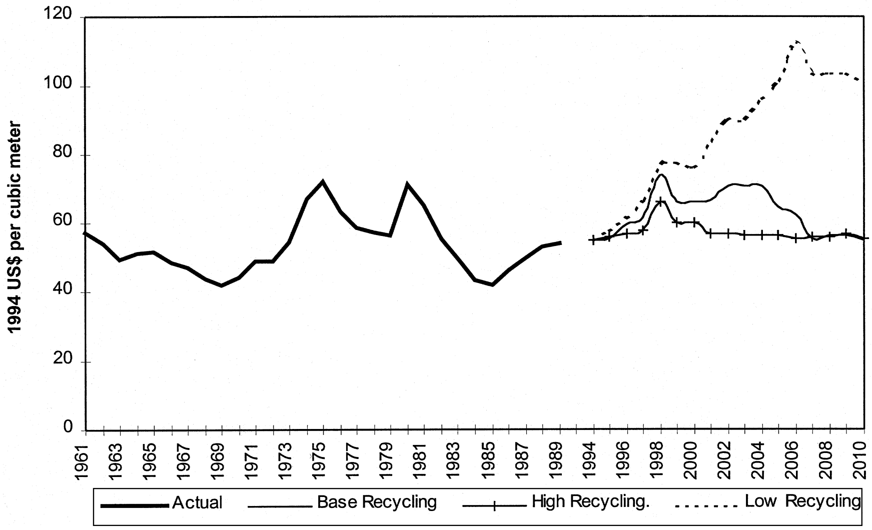

Fig. 12. Pulpwood price, by recycling scenario.

restricted by the timber potential in the base scenario. Hence, paper and paperboard production is higher in the high-recycling scenario which requires less wood input. The price of waste paper remains approximately constant in the different scenarios due to increased waste paper supply.

The technical trends in the use of recycled fiber have also an effect on sawlog-based industries. As the demand for particles coming from sawmill wastes is lower in the high-recycling scenario, the revenue in sawnwood production and hence sawlogs demand and supply are reduced as well. Global sawlogs supply is 1 095 000 000 m^3 in the year 2010 in the high-waste scenario, compared to 1 110 000 000 m^3 in the base scenario. The price effects on sawlogs of the different recycling scenarios are considerable, as shown in Fig. 13.

4. Discussion and conclusions

A dynamic partial equilibrium model, with a structure similar to the one used in FAO (1997), was developed to analyze the future of global timber markets, with particular attention to the differences between pulpwood and sawlogs. An assessment was made of how some key assumptions about economic growth, timber supply, and technology affect the projections of world prices, demand, supply and international trade.

In the base scenario, which represents a plausible development of economic growth, timber supply potential and technical change, the timber supply potential was binding, limiting the average annual increase in global supply at approximately 1.2% until the year 2010. The projected figures for industrial roundwood production were consistent with findings in other studies like FAO (1997), Brooks (1997) and Brooks et al. (1996). The former USSR continued to be the main exporter of sawlogs, pulpwood and particles. Asia and Scandinavia continued to be the main importers. Net export of pulpwood and particles from the USA decreased sharply and the USA became the largest importer of pulpwood and particles by the year 2010.

Whereas the real price of sawlogs, sawnwood and veneer and plywood were found to remain approximately constant, the prices of pulpwood and particles increased significantly at the beginning of the projection period, though they declined after the year 2000. The real prices of intermediate and final products in the pulp and paper sector increased less than those of raw materials. As the capacity constrained the pro-

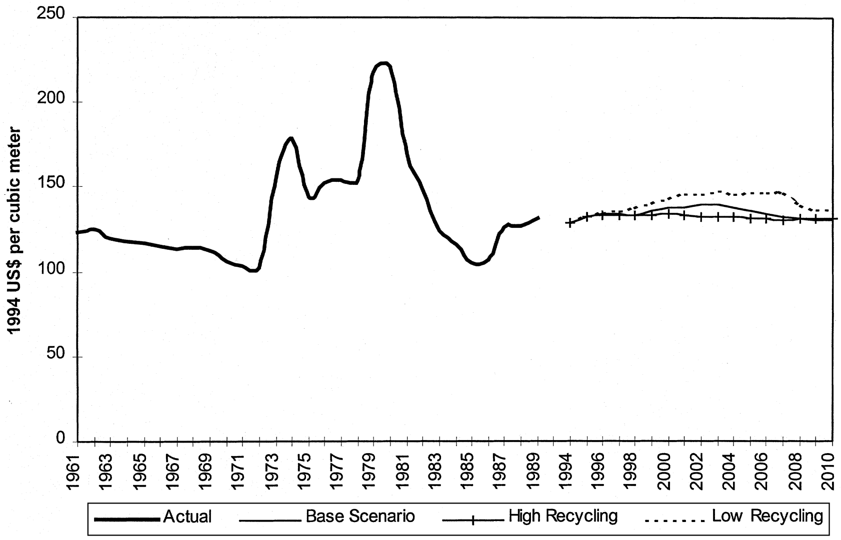

Fig. 13. Sawlogs price, by recycling scenario.

duction of printing and writing paper towards 2010, the real price began to rise.

As the timber supply potential was binding, the variants in GDP growth rates had very limited influence on quantities demanded and supplied. The real prices of pulpwood and particles got significantly higher in scenarios with faster economic growth, whereas the influence on the sawlogs price was modest. The assumptions regarding the timber supply potential affected regional and global pulpwood demand and supply significantly. The real prices of pulpwood and particles almost doubled in the low timber potential scenario, although global production decreased by 80% only. The faster increase in pulpwood price relative to sawlogs in the model is due to the higher income elasticities of demand for paper products than for solid wood products. If a higher fraction of the industrial roundwood supply will consist of pulpwood in the future, due to increase output of young plantations and substitution between pulpwood and sawlogs in timber supply, the actual price increase of pulpwood will be lower than projected here.

A possible increase in potential timber supply from the ex USSR, combined with assumptions about less restricted trade, was able to flatten out the global pulpwood price. The possible increase in timber availability in the former USSR resulted in higher export of timber, but not in significantly higher industrial production in that region. The results of the timber potential scenarios showed that they are among the most critical assumptions in predicting the future development of demand, supply and prices in the forest sector.

A scenario where the timber supply was price responsive and shifted outwards, had a significant impact on the price development, especially for pulpwood. This illustrates the importance of the specification of timber supply and suggests also that a useful improvement of the model would be to make the potential supply constraint price responsive.

Assumptions about technical change bringing about more recycled fiber in paper manufacture affected the results significantly when the timber supply was the limiting factor. Similar to the findings in the timber supply potential scenarios, prices were relatively more affected than production, consumption, and trade when more or less recycled fiber was used in making paper and paperboard.

From the point of view of methods, the applications presented above point out several limitations and possible improvements. In particular, there is only one technology in each region, unaffected by the relative prices of inputs. Even though the substitution possibilities are limited in the forest industries, it is likely that a price increase for industrial roundwood would induce a technical change to reduce the input of wood. Hence, the price of industrial roundwood would increase less than predicted here, with attendant results for wood using industries.

Apart from the attempt to distinguish between sawlogs and pulpwood, the products are still rough aggregates. International trade statistics do not distinguish any more between logs and pulpwood. In general, there are never enough data to model accurately forest industries, especially at the international level. Especially Asian data for countries like China, India and Indonesia are questionable. However, the material balance between raw materials, intermediate and final products imposed by the PELPS structure helps ascertain the plausibility of the data.

The results have shown that the assumptions regarding timber supply are critical. There are many studies of timber supply elasticities, especially for Finland, Sweden and Norway, but the estimates differ widely from study to study (Solberg and Moiseyev, 1997, 1998). Theoretically, change in inventory is an important shift variable for timber supply. As a result, some models attempt to model inventory explicitly (see, e.g. the GTM model in Kallio et al., 1987). But inventory data are very scarce, the magnitude of the inventory elasticities are uncertain, and the timber potential is guided at least as much by political as by economic forces. Thus, modeling timber supply as an exogenous constraint, may still be a suitable alternative.

The parameters of the distributed lag-function that decide the global capacity expansion are the same for all products. Better estimates should be obtained by econometrics, for each product. Due to the importance of capacity expansion, the implications of other investment models such as Tobin's q-model (described by Zhang and Buongiorno, 1993, and usable in PELPSIII) should be investigated.

The results from this study regarding sensitivity of relative price development of pulpwood and sawlog world prices, proved to be valuable data-input for a more detailed national forest sector models.

In the present model, regional net trade is the result of the value and of the cost of products in different regions, and of the trade inertia constraints. Trade inertia constraints are hard to estimate accurately, and they may distort the results (Cardellichio and Adams, 1990). Still, trade flows are not solely decided by prices, and adjustments are bound to take time because of factors such as long-term contracts, information flows and regulations. So, the use of trade inertia parameters may be justified, but their magnitude should be refined by empirical estimates. Another possibility is to develop a more flexible model of trade inertia than simple upper and lower bounds.

In conclusion, the model developed here and the PELPS system on which it is based are helpful in bringing together a wide variety of variables and relationship that bear on the timber market. The results underline the importance of good data in particular for timber potentials, timber supply elasticities and technical coefficients. More work is needed to estimate capacity expansion parameters for individual products. The differences in the price projections for pulpwood and sawlogs favors the idea of separating these products, rather than pooling them as in previous studies, such as FAO (1997), and thus reinstating detailed trade data separating pulpwood from sawlogs.

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