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Long-term effects of eliminating illegal logging on the world forest industries, trade, and inventory

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ABSTRACT

We assessed the impact on the world forest sector of a progressive elimination of illegal logging. The analysis compared predictions from 2007 to 2020, with and without a gradual reduction of illegally logged industrial roundwood from 2007 to 2011. A large part of the curtailment of timber supply due to the stoppage of illegal logging would be compensated by increased legal production incited by higher prices. As a result, without illegal logging the world annual production of industrial roundwood would decrease by no more than 1%, even though it would decrease by up to 8% in developing countries. World prices would rise by 1.5 to 3.5% for industrial roundwood and by 0.5 to 2% for processed products, depending on the assumption on illegal logging rates. World consumer expenditures for wood products and producer revenues would rise by 1 to 2% without illegal logging. World value added in forest industries would remain the same. However, the changes in consumer expenditures would be more than double the changes in producer revenues in countries dependent on illegally logged timber of domestic or foreign origin such as Indonesia and China. Symmetrically, changes in producer revenues would be almost twice the changes in consumer expenditures in countries with little illegal logging and efficient industries, such as Canada, Germany and the United States. Value added in forest industries would decrease most in countries with heavy illegal logging (12% in Indonesia and up to 9% in Brazil), and it would increase most in Germany, Canada (4%), and the United States (2%). Without illegal logging, the world forest inventory would increase slightly, as the increase in developing countries would more than compensate the decrease in developed countries.

1. Introduction

Illegally logged timber and its associated international trade is a major problem for environmental, economic, and social reasons. While logging may be a less direct cause of deforestation than land conversion for agriculture (Geist and Lambin, 2002), illegal logging raises concerns about over-exploitation and poor forest management. Because much of illegal harvesting is in tropical forests, it hampers important environmental services (Kinnaird et al., 2003, Bala et al., 2007), such as the habitat of the great apes in Africa (Walsh et al., 2003), and of the orangutan and Sumatran tiger (Jepson et al., 2001, Nellemann et al., 2007).

In terms of economics, the World Bank (2002) estimates that illegal logging reduces government revenues by about $US5 billion a year. Less direct, but much larger is the effect of the unsanctioned harvests of extra wood on global markets, which depresses prices and reduces the incentives for managing forests sustainably. As illegal logging is very profitable to a few in the short run, it often coexists with corruption, undermining the rule of law and good governance (Jepson et al., 2001, McElwee, 2004; Bulkan and Palmer, 2006).

Accordingly, conservation groups, industries, governments, and multinational organizations are promoting policies to combat illegal logging practices and to stop imports of illegal wood products (G8, 1998; United Nations Forum on Forests, 2002; Brack 2006; Sheikh, 2007). Nonetheless, economic, social, and ecological data on the effects of illegal logging are still scarce, especially at international level. Previous studies such as Seneca Creek Associates (2004) focused on effects on the United States, while Turner et al. (2007) were mostly concerned about the implications for New Zealand.

Without denying the environmental importance of illegal logging, the objective of this study was to assess its economic effects on forest industries by predicting how markets would change if illegal logging were gradually eliminated over five years. The predictions are global, and by major country and industry (logging, sawmilling, etc.). In addition to the effects on forest stock, production, consumption, imports, exports, and prices of various products, data were also obtained on producer revenues, consumer expenditures, and on value added to locate gains and losses and to follow them over fifteen years.

The remainder of the paper consists of a brief presentation of the methods, followed by a description of the different effects in major

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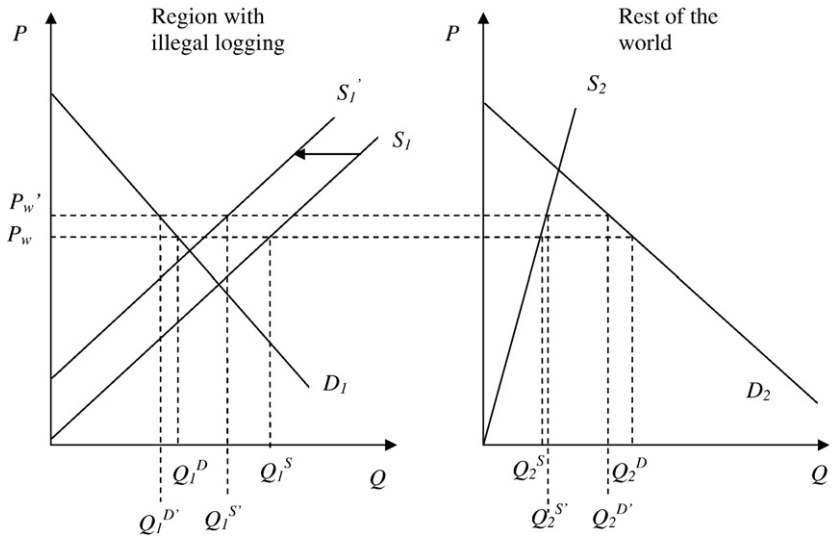

Fig. 1. World competitive equilibrium in international wood markets with and without illegal logging.

producing and trading countries, economic groups, and for world regions. It is found that although eliminating illegal logging would have a small relative effect at the global level, the impact would vary considerably by country according to the extent of local illegal logging or the dependency of industry on imported timbers.

2. Methods

The international effects of gradually eliminating the supply of illegally logged timber were simulated with the Global Forest Products Model (GFPM) (Buongiorno et al., 2003; Zhu et al., 2006a,b). Initially developed for the United Nations Food and Agriculture Organization (FAO) Global Forest Products Outlook studies, the GFPM is a dynamic spatial equilibrium model which predicts production, imports, exports, and prices of 14 forest products in 180 individual countries.

Among the variables of the GFPM are supplies, imports and exports of industrial roundwood, by country. Demand and supply of each product are represented by econometric functions and by activity analysis. Trade is driven by the economic growth of the countries and by their relative competitive advantage. The equilibrium in each year is found by maximizing the quasi welfare of the world forest sector: the value of the products to consumers, minus their cost of production and transport. Equilibrium prices are the shadow prices of the material balance constraints in each country, such that, for each product and country, demand equals domestic production plus imports minus exports.

The mathematical specification of the GFPM is given in Buongiorno et al. (2003). The most recent improvements, including prediction of changes in forest area and forest stock (Turner et al., 2006a), are described in Zhu et al. (2006a,b).

The theory underlying the experiment carried out with the GFPM for this particular study is sketched in Fig. 1. It symbolizes the demand for and supply of wood in regions where there is illegal logging and in the rest of the world. The figure shows two market equilibria: with illegal logging, and without it. An assumption embodied in Fig. 1 is that illegally logged wood is a perfect substitute for (is identical too) legally logged wood.

With illegal logging, the world price of wood is P_w. In reality, and within the GFPM the price in the importing region (here, the rest of the world) is the price in the exporting region (here, the region with illegal logging), plus the transport cost. For simplicity, and without loss of generality, Fig. 1 omits the transport cost. At price P_w the world supply of wood is equal to the world demand, and the net exports, $Q_1^S - Q_1^D$, of the region where there is illegal logging are equal to the net imports, $Q_2^D - Q_2^S$, of the rest of the world.

Elimination of illegal logging is equivalent to a leftward shift of the supply curve S_1 to S_1'. The magnitude of this leftward shift depends on the illegal logging rate. The new equilibrium occurs at a higher price, P_w'. The quantity supplied in the region with illegal logging decreases to $Q_1^{S'}$. This decrease is less than the leftward shift of supply because the price increase induces an increase in legal logging. This compensation follows the Le Chatelier–Samuelson principle (Samuelson, 1947) according to which "if the conditions of a system, initially at equilibrium, are changed, the equilibrium will shift in such a direction as to tend to restore the original conditions" (Pauling, 1964).

The net exports of the region where there was illegal logging decrease even though the domestic consumption also decreases from Q_1^D *to* $Q_1^{D'}$ due to the increase in price. In some conditions, the region could change from net exporter to net importer. The direction and magnitude of the change in the gross revenues of producers, from $P_w \times Q_1^S$ *to* $P_w' \times Q_1^{S'}$ depends on the current rate of illegal logging in the region and on the elasticity of the supply curve. The change in the expenditures of consumers depends also on the elasticity of demand.

In the rest of the world, the halting of illegal logging decreases consumption and increases production due to the increase in price. As a result, the net imports decrease, and the region could even become a net exporter in some instances. In Fig. 1, the producers' gross revenue would increase from $P_w \times Q_2^S$ *to* $P_w' \times Q_2^{S'}$. However, the magnitude and direction of the change in producer revenues, and of the change in consumer expenditures (from $P_w \times Q_2^D$ *to* $P_w' \times Q_2^{D'}$) depends on the elasticities of supply and demand.

The GFPM computations follow the principle of spatial market equilibrium symbolized by Fig. 1. However, the magnitude and even the direction of these effects cannot be predicted as simply. The GFPM depicts not only the world market for industrial roundwood, but also the markets of all of the products (sawnwood, panels, and pulp and paper) that use industrial roundwood as an input. Thus, a decrease in illegal logging can have extensive repercussions on the production, consumption, trade, and prices of other products in many countries.

An example of the GFPM structure, with two countries and three products, is presented in the Appendix. This example illustrates how production in a country is affected by the shift of wood supply in another country due to the elimination of illegal logging. According to equilibrium theory, markets maximize producer and consumer surplus across all countries and products. Thus, changes depend in part on the relative cost and efficiency of wood production and

Table 1
Estimated share of illegally logged industrial roundwood in 2004

	Sawlogs		Pulpwood	
	High	Low	High	Low
AFRICA				
Algeria	0.28	0.25	0.28	0.25
Angola	0.28	0.25	0.28	0.25
Benin	0.80[a]	0.25	0.00	0.00
Botswana	0.28	0.25	0.00	0.00
Burkina Faso	0.28	0.25	0.00	0.00
Burundi	0.28	0.25	0.00	0.00
Cameroon	0.50	0.25	0.00	0.00
Cape Verde	0.28	0.25	0.00	0.00
Central African Rep.	0.28	0.25	0.00	0.00
Chad	0.28	0.25	0.00	0.00
Congo	0.28	0.25	0.28	0.25
Cote d'Ivoire	0.30	0.25	0.00	0.00
Djibouti	0.28	0.25	0.00	0.00
Egypt	0.28	0.25	0.00	0.00
Equatorial Guinea	0.28	0.25	0.00	0.00
Ethiopia	0.28	0.25	0.28	0.25
Gabon	0.28	0.25	0.00	0.00
Gambia	0.28	0.25	0.00	0.00
Ghana	0.28[a]	0.25	0.00	0.00
Guinea	0.66	0.40	0.00	0.00
Guinea-Bissau	0.28	0.25	0.00	0.00
Kenya	0.28	0.25	0.25	0.25
Lesotho	0.28	0.25	0.00	0.00
Liberia	0.50	0.25	0.00	0.00
Libya	0.28	0.25	0.00	0.00
Madagascar	0.28	0.25	0.25	0.25
Malawi	0.28	0.25	0.00	0.00
Mali	0.28	0.25	0.00	0.00
Mauritania	0.28	0.25	0.00	0.00
Mauritius	0.28	0.25	0.00	0.00
Morocco	0.16	0.10	0.00	0.00
Mozambique	0.60[a]	0.25	0.00	0.00
Niger	0.28	0.25	0.28	0.25
Nigeria	0.30	0.25	0.00	0.00
Reunion	0.28	0.25	0.00	0.00
Rwanda	0.28	0.25	0.00	0.00
Sao Tome and Princ	0.28	0.25	0.00	0.00
Senegal	0.28	0.25	0.00	0.00
Sierra Leone	0.28	0.25	0.00	0.00
Somalia	0.28	0.25	0.00	0.00
South Africa	0.00	0.00	0.00	0.00
Sudan	0.28	0.25	0.00	0.00
Swaziland	0.28	0.25	0.25	0.25
Tanzania	0.28	0.25	0.00	0.00
Togo	0.28	0.25	0.00	0.00
Tunisia	0.28	0.25	0.28	0.25
Uganda	0.28	0.25	0.00	0.00
Zaire	0.28	0.25	0.00	0.00
Zambia	0.28	0.25	0.00	0.00
Zimbabwe	0.05	0.05	0.05	0.05
N/C AMERICA				
Bahamas	0.20	0.10	0.00	0.00
Barbados	0.20	0.10	0.00	0.00
Belize	0.20	0.10	0.00	0.00
Canada	0.00	0.00	0.00	0.00
Cayman Islands	0.20	0.10	0.00	0.00
Costa Rica	0.25[b]	0.20	0.10	0.10
Cuba	0.20	0.10	0.00	0.00
Dominica	0.20	0.10	0.00	0.00
Dominican Rep.	0.20	0.10	0.00	0.00
El Salvador	0.20	0.10	0.00	0.00
Guatemala	0.20	0.10	0.00	0.00
Haiti	0.20	0.10	0.00	0.00
Honduras	0.60[a]	0.20	0.25	0.25
Jamaica	0.20	0.10	0.00	0.00
Martinique	0.20	0.10	0.00	0.00
Mexico	0.10	0.10	0.20	0.10
Netherlands Antilles	0.20	0.10	0.00	0.00
Nicaragua	0.42[a]	0.10	0.00	0.00
Panama	0.20	0.10	0.20	0.10
Saint Vincent	0.20	0.10	0.00	0.00
Trinidad and Tobago	0.20	0.10	0.00	0.00
United States of A.	0.00	0.00	0.00	0.00
Argentina	0.03	0.02	0.03	0.02
Bolivia	0.80[a]	0.05	0.00	0.00
Brazil	0.80[a]	0.05	0.00	0.00
Chile	0.02	0.02	0.00	0.00
Colombia	0.42[a]	0.10	0.00	0.00
Ecuador	0.70[a]	0.20	0.10	0.10
French Guiana	0.20	0.20	0.00	0.00
Guyana	0.20	0.20	0.00	0.00
Paraguay	0.20	0.20	0.00	0.00
Peru	0.80[b]	0.20	0.10	0.00
Suriname	0.20	0.20	0.00	0.00
Uruguay	0.08	0.00	0.00	0.00
Venezuela	0.04	0.02	0.04	0.00
ASIA				
Afghanistan	0.13	0.10	0.00	0.00
Bahrain	0.00	0.00	0.00	0.00
Bangladesh	0.30[b]	0.30	0.30	0.30
Bhutan	0.20	0.05	0.00	0.00
Brunei	0.00	0.00	0.00	0.00
Cambodia	0.90[a]	0.30	0.00	0.00
China	0.50[b]	0.30	0.50	0.20
Cyprus	0.00	0.00	0.00	0.00
Hong Kong	0.00	0.00	0.00	0.00
India	0.10	0.10	0.10	0.05
Indonesia	0.80[a]	0.50	0.30	0.20
Iran	0.10	0.05	0.20	0.20
Iraq	0.10	0.05	0.00	0.00
Israel	0.00	0.00	0.00	0.00
Japan	0.00	0.00	0.00	0.00
Jordan	0.10	0.05	0.00	0.00
Kazakhstan	0.10	0.10	0.10	0.10
Korea, DPR	0.00	0.00	0.00	0.00
Korea, Rep.	0.00	0.00	0.00	0.00
Kuwait	0.00	0.00	0.00	0.00
Kyrgyzstan	0.10	0.10	0.00	0.00
Laos	0.40	0.30	0.00	0.00
Lebanon	0.00	0.00	0.00	0.00
Macau	0.00	0.00	0.00	0.00
Malaysia	0.33[a]	0.05	0.10	0.05
Moldova, Rep.	0.10	0.10	0.00	0.00
Mongolia	0.10	0.00	0.00	0.00
Myanmar	0.80[a]	0.40	0.40	0.20
Nepal	0.10	0.10	0.00	0.00
Oman	0.00	0.00	0.00	0.00
Pakistan	0.25	0.10	0.20	0.20
Philippines	0.30	0.25	0.20	0.20
Qatar	0.00	0.00	0.00	0.00
Saudi Arabia	0.00	0.00	0.00	0.00
Singapore	0.00	0.00	0.00	0.00
Sri Lanka	0.10	0.10	0.20	0.20
Syria	0.07	0.05	0.00	0.00
Tajikistan	0.10	0.10	0.00	0.00
Thailand	0.40	0.30	0.20	0.00
Turkey	0.00	0.00	0.00	0.00
Turkmenistan	0.10	0.10	0.00	0.00
UAE	0.00	0.00	0.00	0.00
Uzbekistan	0.10	0.10	0.00	0.00
Viet Nam	0.30	0.30	0.30	0.00
Yemen	0.00	0.00	0.00	0.00
OCEANIA				
Australia	0.00	0.00	0.00	0.00
Cook Islands	0.20	0.20	0.00	0.00
Fiji Islands	0.20	0.20	0.00	0.00
French Polynesia	0.20	0.20	0.00	0.00
New Caledonia	0.20	0.20	0.00	0.00
New Zealand	0.00	0.00	0.00	0.00
Papua New Guinea	0.65[b]	0.20	0.65	0.20
Samoa	0.20	0.20	0.00	0.00
Solomon Islands	0.20	0.20	0.00	0.00
Tonga	0.20	0.20	0.00	0.00
Vanuatu	0.20	0.20	0.00	0.00
EUROPE				
Albania	0.90[a]	0.10	0.00	0.00
Armenia	0.10	0.10	0.00	0.00
Austria	0.00	0.00	0.00	0.00

Table 1 (*continued*)

	Sawlogs		Pulpwood	
	High	Low	High	Low
Azerbaijan, Rep.	0.80[a]	0.10	0.80	0.10
Belarus	0.10	0.10	0.10	0.03
Belgium	0.00	0.00	0.00	0.00
Bosnia-Herzegovina	0.10	0.10	0.10	0.10
Bulgaria	0.45[a]	0.10	0.10	0.10
Croatia	0.10	0.10	0.10	0.10
Czech Rep.	0.10	0.10	0.05	0.05
Denmark	0.00	0.00	0.00	0.00
Estonia	0.50[b]	0.10	0.10	0.03
Finland	0.00	0.00	0.00	0.00
France	0.00	0.00	0.00	0.00
Georgia	0.85[a]	0.10	0.00	0.00
Germany	0.00	0.00	0.00	0.00
Greece	0.00	0.00	0.00	0.00
Hungary	0.10	0.10	0.00	0.00
Iceland	0.00	0.00	0.00	0.00
Ireland	0.00	0.00	0.00	0.00
Italy	0.00	0.00	0.00	0.00
Latvia	0.20[b]	0.10	0.20	0.10
Lithuania	0.10	0.10	0.00	0.00
Macedonia, The Fmr	0.10	0.10	0.00	0.00
Malta	0.10	0.10	0.00	0.00
Netherlands	0.00	0.00	0.00	0.00
Norway	0.00	0.00	0.00	0.00
Poland	0.10	0.10	0.10	0.03
Portugal	0.00	0.00	0.00	0.00
Romania	0.10	0.10	0.10	0.03
Russian Federation	0.30[a]	0.20	0.20	0.15
Serbia and Montenegro	0.10	0.10	0.10	0.03
Slovakia	0.10	0.10	0.10	0.03
Slovenia	0.10	0.10	0.10	0.03
Spain	0.00	0.00	0.00	0.00
Sweden	0.00	0.00	0.00	0.00
Switzerland	0.00	0.00	0.00	0.00
Ukraine	0.10	0.10	0.10	0.03
United Kingdom	0.00	0.00	0.00	0.00

[a] Contreras-Hermosilla et al. (2007) pp. 8–9.
[b] Miller et al. (2006). Other high estimates for sawlogs from Seneca Creek Associates (2004). Low sawlog estimates and pulpwood estimates by Alberto Goetzl, Seneca Creek Associates.

transformation for different countries and products. Changes also depend on the relative value of the end products to consumers in different countries. Thus, predicting what will happen to production is more complex than in the case of two countries and one product illustrated in Fig. 1.

Furthermore, adjustments take time. This interdependence and inertia, which are explicit in the GFPM, are absent in the simple comparative statics illustrated by Fig. 1. Another benefit of the GFPM is that its manufacturing activities describe in detail the transformation of raw materials, such as industrial roundwood, into intermediate products such as wood pulp, and end products such as paper and paperboard, thus allowing the computation of value added: the value of the end products minus the cost of the intermediate wood and fiber products.

The effects of a progressive elimination of illegal logging were obtained by comparing three sets of projections with the GFPM. The "base" scenario, made the same assumptions as the World Wood Industries Outlook, which had also been prepared with the GFPM (Turner et al., 2006b). There was no change in the extent of illegal logging in the "base" case. According to the Outlook, the world annual production of industrial roundwood would increase by 640 million m^3 (38%) from 2005 to 2020.

Two "without illegal logging" scenarios made the same assumptions as the base scenario, except that the supply of industrial roundwood was reduced gradually from 2007 to 2011 by the amount of illegal logging assumed in each country. This was implemented with the supply shifters of the GFPM, which allow exogenous shifts of the supply of industrial roundwood analog to the shift shown in Fig. 1 (Buongiorno et al., 2003, p. 45). Thus, except for the rate of illegal logging, the assumptions were the same in all three scenarios. In particular, the exchange rates, which are notoriously hard to predict, were held constant. This is legitimate for a policy analysis concentrating on the effects of eliminating illegal logging, other things being equal.

The two "without illegal logging" scenarios differed by the assumed initial rate of illegal logging. The "high" and "low" rates, defined by the percent of total production that was from illegal sources are in Table 1. Most of the data were from Seneca Creek Associates (2004), supplemented by other authors' estimates (Miller et al., 2006; Contreras-Hermosilla et al., 2007) as indicated in Table 1. The low estimates were those used by Seneca Creek Associates adjusted downward to reflect more conservative assumptions. Seneca Creek also provided assumptions to take into account that the amount of illegal or suspicious material in the pulp industry is very different than it is for solid wood products. In Brazil, for example, most of the fiber that goes into the pulp and paper industry is plantation-based and entirely legal while hardwood from the Amazon forest allegedly includes much illegally harvested material. As the GFPM deals with industrial roundwood only, which is the sum of sawlogs and pulpwood, the rate of illegal logging was the average of the rates for sawlogs and pulpwood, weighted by their production in 2004. The high and low rates in Table 1 imply that the world rate of illegal logging of industrial roundwood was between 6% and 12% of global production in 2004.

Both the base and the "without illegal logging" projections were continued until 2020. The projections were then compared in terms of production, consumption, imports, exports, prices, producer revenues, consumer expenditures, and value added.

3. Results

The effects from 2007 to 2020 of a gradual elimination of illegal logging from 2007 to 2011 on various parts of the world forest sector are summarized in Tables 2–8. This decrease in industrial roundwood supply affected the forest inventory, the trade of all forest products, the distribution of production, and the prices, with consequences for producer revenues, consumer expenditures, and value added.

3.1. Effects on industrial roundwood

The gradual elimination of illegal logging reduced annual production of industrial roundwood in developing countries by 3 to 8% from 2007 to 2020, depending on the assumption on illegal logging rates (Table 2). However, about half of this decrease was compensated by higher production in developed countries. As the world price[1] of all wood products increased (Table 3), the derived demand for industrial roundwood increased to cancel part of the loss of supply from illegal logging. Consequently, world production decreased by only 1% assuming the high initial rate of illegal logging, and half of a percent with the low rate.

Nevertheless, the logging activity in some countries that are currently major exporters of industrial roundwood was seriously curtailed without illegal logging. The main decrease in production occurred in the Russian Federation, China, Indonesia, and Brazil. On the other hand, logging increased substantially in countries where there was little illegal logging, in Europe, North America, New Zealand, Japan, and Chile (Table 2).

Meanwhile, with the progressive elimination of illegal logging, the world annual trade of industrial roundwood decreased more than production in relative terms. World imports and exports decreased by 2 to 6% depending on the assumption on the initial illegal logging rate. Exports decreased most in the Russian Federation and Malaysia, while they grew most in Chile, the United States and New Zealand.

[1] World prices are weighted averages of prices in different countries, the amounts of yearly national consumption serving as weights.

Symmetrically, imports of industrial roundwood decreased mostly in Japan, and Finland. In Sweden and Canada, imports decreased much more with the high initial illegal logging rate assumption than with the low.

Fig. 2 shows the path of industrial roundwood production, price, and value of production in the Russian Federation, where illegal logging is deemed substantial, with or without illegal logging. With the high illegal logging assumption, production grew little up to 2011 as illegal logging was progressively suppressed, but it then climbed at almost the same rate as it would have with continuing illegal logging.

With the tightening of supply from 2007 to 2011, the real price of industrial roundwood in the Russian Federation stayed almost constant rather than decline steadily as it did with continued illegal logging. However, after 2011 the price followed a path parallel to the price predicted with illegal logging. The price predictions were similar with the high assumed initial rates of illegal logging as with the low rates.

Because the relative price increase induced by the elimination of illegal logging was larger than the relative decrease in production, the value of production (i.e., the gross revenue of industrial roundwood producers), was higher than with continued illegal logging.

3.2. Effects on sawnwood

The gradual elimination of illegal logging from 2007 to 2011 decreased the annual production of sawnwood in developing countries by 2 to 5% from 2007 to 2020, depending on the assumed initial illegal logging rate (Table 4). But production increased in developed countries, compensating for more than half of the decline in developing countries. In conjunction with the lower global supply and unchanged demand, the world price of sawnwood increased by 0.5 to 1.3%, a third of the rise in the price of industrial roundwood (Table 3).

Sawnwood production decreased substantially in countries with high illegal logging such as the Russian Federation and Indonesia, and in countries that import logs, such as China, Sweden and Finland (Table 4). In countries that utilize domestic harvests, sawnwood production increased. For example, United States production increased by 5 to 11%.

Table 2
Average changes in annual industrial roundwood production and trade from 2007 to 2020 due to the progressive elimination of illegal logging

	Production		Imports		Exports	
	High[b]	Low[b]	High	Low	High	Low
	10^3 m^3					
AFRICA[a]	−1857	−2158	8	3	352	−252
NORTH and CENTRAL AMERICA	25,374	10,888	−2172	−10	1371	975
Canada	6093	2399	−2180	−17	0	0
United States of America	20,290	9451	0	0	1388	981
SOUTH AMERICA	−18,927	−1526	1	0	1216	188
Brazil	−18,593	−770	0	0	−3	3
Chile	697	129	0	0	1188	170
ASIA	−23,975	−13,859	−662	−288	−5108	−1320
China	−12,048	−6701	7	7	0	0
Indonesia	−5251	−4578	106	80	−22	−22
Japan	886	363	−268	−300	0	0
Malaysia	−5187	−478	0	0	−4463	−493
OCEANIA	876	261	0	0	1193	424
New Zealand	924	377	0	0	793	361
EUROPE	−8137	−4644	−8628	−3364	−10,478	−3673
EU-25	6112	1345	−7795	−3039	−106	−159
Finland	2894	1392	−3934	−2168	0	0
Germany	2320	947	0	0	1	0
Sweden	2190	789	−2237	−89	0	0
Russian Federation	−12,785	−4390	0	0	−10,715	−3654
DEVELOPED, ALL	22,256	8842	−11,082	−3682	−5688	−1201
DEVELOPING, ALL	−48,828	−19,826	−372	22	−5766	−2458
WORLD	−26,572	−10,984	−11,454	−3659	−11,454	−3659

[a] Regions are defined as in FAO (2006).
[b] Illegal logging rates (Table 1).

Table 3
Increase in world prices due to the progressive elimination of illegal logging

Product[a]	2007		2011		2020	
	High[b]	Low[b]	High	Low	High	Low
	%					
Industrial roundwood	0.6	0.3	3.8	1.8	4.2	1.6
Sawnwood	0.1	0.1	1.3	0.5	1.8	0.7
Veneer and plywood	0.5	0.2	2.3	0.7	2.0	0.7
Particleboard	0.2	0.1	0.8	0.4	1.2	0.5
Fiberboard	0.2	0.1	1.0	0.4	1.2	0.5
Mechanical pulp	0.2	0.1	1.2	0.6	1.4	0.5
Chemical pulp	0.3	0.1	1.3	0.5	1.6	0.6
Waste paper	0.1	0.0	0.4	0.2	1.2	0.9
Newsprint	0.1	0.1	0.6	0.3	0.8	0.3
Printing and writing paper	0.1	0.1	0.5	0.3	0.6	0.4
Other paper and paperboard	0.1	0.0	0.3	0.2	0.4	0.1

[a] Defined as in FAO (2006).
[b] Illegal logging rates (Table 1).

The world trade was affected more than production in relative terms, decreasing by 3 to 8% depending on the initial illegal logging rate. An important change in trade occurred for the United States, which decreased its imports of sawnwood by 13 to 30% when illegal logging was eliminated. However, the United States exports were unaffected so that the increased domestic production went to substitute imports. Meanwhile, exports of Canada, which go largely to the United States, decreased by 3 to 9%.[2] Exports from the Russian Federation, Sweden, and Finland, also decreased. The example in the Appendix with two countries and three products, illustrates how, in the context of a general increase in prices induced by lower timber supply, manufacturing may shift from products of relatively low value such as sawnwood to higher valued products such as panels and pulp and paper.

3.3. Effects on wood-based panels

Without illegal logging the production of wood-based panels would decrease in developing countries by 2 to 7%, while in developed countries production would increase by 1 to 2%, depending on the assumption on the initial illegal logging rates (Table 5). As a result, world production was only 1% lower. In conjunction with this lower supply, and unchanged demand, the price of panels was 0.5% to 2% higher from 2007 to 2020.

The largest decrease in wood-based panel production was in countries with high levels of illegal logging, or countries that depended on imported logs. The most affected countries, regardless of the initial illegal logging rates, were China, the Russian Federation, and Indonesia. For Indonesia there was a concurrent large decline in exports. For Brazil and Malaysia, the magnitude of the decrease in production depended heavily on the assumed initial illegal logging rates.

Meanwhile, without illegal logging, production of wood-based panels was stimulated in countries that had initially little illegal logging. The largest increase was in the United States, where annual production increased by 1 to 2.5 million m^3, and concurrently imports declined by an equal amount. In contrast, in Canada and New Zealand, the increase in production translated into an almost equal rise of

[2] Although Canada is a major lumber exporter and would seem to benefit from globally higher lumber prices, Canadian forest product producers benefit relatively more in other industries, especially wood-based panels and paper. The effect of this relative profit shift is to divert roundwood use away from lumber and toward panel and paper manufacture. This diversion causes domestic and export lumber supply to shift back. The decrease in Canadian exports, mostly to the United States, is compensated by the increase in US domestic production. Another reason for the backward shift in lumber supply is Canada's slight reduction in forest stocks that occurs from greater harvest pressure to provide the additional roundwood demanded by the paper and panel industries.

Table 4
Average changes in annual sawnwood production and trade from 2007 to 2020 due to the progressive elimination of illegal logging

Region	Production		Imports		Exports	
	High[b]	Low[b]	High	Low	High	Low
	10^3m^3					
AFRICA[a]	−727	−585	134	95	−457	−388
NORTH and CENTRAL AMERICA	7043	3420	−10,917	−4600	−3563	−1035
Canada	−3596	−1048	0	0	−3549	−1029
United States of America	11,200	5035	−11,408	−5133	0	0
SOUTH AMERICA	−2520	−266	2	0	−2099	−216
Brazil	−1998	−31	0	0	−1672	−4
Chile	−241	−28	0	0	−227	−22
ASIA	−1680	−1116	179	194	−342	−296
China	−739	−412	11	11	0	0
Indonesia	−243	−106	68	18	−2	−2
Japan	−47	−59	2	41	0	0
Malaysia	−17	−6	0	0	−4	−1
OCEANIA	−41	−11	2	0	−24	−4
New Zealand	−12	−6	0	0	−6	−3
EUROPE	−4511	−2605	554	481	−3561	−1890
EU-25	−2405	−1315	108	190	−2081	−1028
Finland	−587	−437	0	0	−570	−429
Germany	33	−7	0	0	61	5
Sweden	−715	−112	0	0	−701	−107
Russian Federation	−813	−135	0	0	−671	−14
DEVELOPED, ALL	3015	1311	−10,851	−4611	−7116	−2922
DEVELOPING, ALL	−5452	−2473	805	783	−2929	−907
WORLD	−2437	−1163	−10,045	−3829	−10,045	−3829

[a] Regions are defined as in FAO (2006).
[b] Illegal logging rates (Table 1).

Table 6
Average changes in annual pulp and paper production and trade from 2007 to 2020 due to the progressive elimination of illegal logging

Region	Production		Imports		Exports	
	High[b]	Low[b]	High	Low	High	Low
	10^3 t					
AFRICA[a]	−186	−155	45	45	−65	−53
NORTH and CENTRAL AMERICA	3423	2082	12	10	2955	1691
Canada	3550	2145	0	0	2954	1690
United States of America	−87	−36	−10	−8	0	0
SOUTH AMERICA	−2546	−247	274	36	−1823	−181
Brazil	−2366	−194	190	4	−1788	−178
Chile	−42	−5	3	0	−36	−3
ASIA	−4558	−4197	748	809	−1309	−1316
China	−1765	−1536	486	557	0	0
Indonesia	−2970	−2733	319	220	−1426	−1425
Japan	−10	3	−7	−9	0	0
Malaysia	−7	2	2	−3	0	0
OCEANIA	−207	−73	57	32	−88	−22
New Zealand	−27	−4	−2	−3	−9	3
EUROPE	1892	1300	−1004	−177	462	635
EU-25	2124	1450	−1071	−225	530	667
Finland	−108	−2	0	0	−75	−3
Germany	1218	590	−769	−246	235	197
Sweden	411	481	0	0	357	328
Russian Federation	−99	−64	0	0	−33	−13
DEVELOPED, ALL	5074	3321	−960	−165	3290	2286
DEVELOPING, ALL	−7256	−4610	1091	919	−3158	−1532
WORLD	−2182	−1289	132	754	132	754

[a] Regions are defined as in FAO (2006).
[b] Illegal logging rates (Table 1).

exports, while in Germany the added production came with higher exports but also lower imports.

Fig. 3 shows the predicted production, price, and value of production (i.e., producer revenues) for the commodity group "veneer and plywood" in Indonesia, with continuing illegal logging or without illegal logging. In all three scenarios, production decreased steadily throughout the projection period. With progressive elimination of illegal logging from 2007 to 2011, production decreased faster than with continued illegal logging. But after 2011, production decreased in parallel with what it would have been with illegal logging.

With the decrease of industrial roundwood supply from 2007 to 2011, the real price of veneer and plywood in Indonesia increased sharply (by 20% assuming high initial illegal logging rates). But after 2011 the price progressively decreased and followed a path parallel to the one with continued illegal logging.

Table 5
Average changes in annual wood based panel production and trade from 2007 to 2020 due to the progressive elimination of illegal logging

Region	Production		Imports		Exports	
	High[b]	Low[b]	High	Low	High	Low
	10^3m^3					
AFRICA[a]	−142	−152	6	12	−114	−127
NORTH and CENTRAL AMERICA	3611	1210	−2722	−1201	1093	103
Canada	1105	119	0	0	1123	126
United States of America	2549	1122	−2723	−1203	0	0
SOUTH AMERICA	−2146	−90	79	5	−1994	−75
Brazil	−2094	−9	71	2	−1963	−2
Chile	7	5	0	0	10	6
ASIA	−4452	−2158	868	130	−1097	−666
China	−2923	−1274	638	9	−13	−13
Indonesia	−348	−256	40	5	−196	−196
Japan	118	−4	−147	−8	0	0
Malaysia	−490	−34	0	0	−485	−32
OCEANIA	59	−8	−82	−21	−9	−24
New Zealand	97	13	0	0	100	15
EUROPE	39	250	−369	53	−99	−232
EU-25	562	350	−661	−196	67	−165
Finland	−20	−68	21	14	4	−52
Germany	944	481	−270	−53	707	441
Sweden	67	32	−72	−34	0	0
Russian Federation	−377	−294	325	244	−4	−9
DEVELOPED, ALL	3905	453	−3338	−1184	1040	−131
DEVELOPING, ALL	−6934	−1918	1118	163	−3260	−890
WORLD	−3029	−1127	−2219	−1021	−2219	−1021

[a] Regions are defined as in FAO (2006).
[b] Illegal logging rates (Table 1).

Table 7
Changes in forest stock due to a gradual elimination of illegal logging

Region	2008		2015		2020	
	High[b]	Low[b]	High	Low	High	Low
	10^6m^3					
AFRICA[a]	0	0	8	12	18	25
NORTH and CENTRAL AMERICA	−3	−1	−144	−59	−352	−137
Canada	−1	0	−43	−15	−91	−31
United States of America	−2	−1	−107	−50	−273	−119
SOUTH AMERICA	3	0	121	9	294	19
Brazil	3	0	119	5	287	9
Chile	0	0	−5	−1	−9	−2
ASIA	4	2	133	73	305	172
China	1	1	64	35	160	89
Indonesia	1	1	27	23	60	51
Japan	0	0	−7	−3	−13	−5
Malaysia	1	0	33	3	64	6
OCEANIA	0	0	−10	−3	−17	−4
New Zealand	0	0	−7	−3	−14	−5
EUROPE	1	0	51	29	106	62
EU-25	0	0	−33	−6	−76	−15
Finland	0	0	−19	−8	−41	−18
Germany	0	0	−15	−5	−34	−12
Sweden	0	0	−17	−5	−33	−10
Russian Federation	0	0	104	25	227	56
DEVELOPED, ALL	−3	−1	−113	−48	−276	−110
DEVELOPING, ALL	7	3	257	109	605	246
WORLD	4	2	145	61	329	136

[a] Regions are defined as in FAO (2006).
[b] Illegal logging rates (Table 1).

Table 8
Average annual changes in producer revenues, consumer expenditures, and value added in forest industries due to the progressive elimination of illegal logging, in 2005 US$

Region	Producer revenues		Consumer expenditures		Value added	
	High[b]	Low[b]	High	Low	High	Low
	US$ 10^6					
AFRICA[a]	22	−67	173	102	−101	−90
NORTH and CENTRAL AMERICA	6505	3093	3179	1528	1978	998
Canada	1965	1057	775	419	693	445
United States of America	4570	2126	2316	1087	1347	610
SOUTH AMERICA	−1207	−21	174	69	−775	−58
Brazil	−1274	9	48	51	−700	−30
Chile	57	31	27	18	−24	−2
ASIA	2573	423	5940	2665	−1707	−1295
China	2301	1059	4646	2396	−776	−502
Indonesia	274	−634	893	100	−809	−723
Japan	344	131	351	143	38	3
Malaysia	−259	16	21	23	−95	−2
OCEANIA	126	48	61	32	−29	−16
New Zealand	109	39	30	11	14	2
EUROPE	2967	1415	1590	805	800	416
Finland	353	159	193	88	−67	−40
Germany	1023	485	355	173	564	267
Sweden	420	319	16	155	42	90
Russian Federation	614	892	683	629	−129	−65
WORLD	11,375	5606	11,801	5811	−74	−207

[a] Regions are defined as in FAO (2006).
[b] Illegal logging rates (Table 1).

Because the relative increase in price was larger than the relative decrease in production, the value of production, or gross revenue of Indonesian producers was substantially higher in the scenario without illegal logging (17% higher with the assumption of high initial illegal logging rates).

3.4. Effects on pulp and paper

The predicted effects of the elimination of illegal logging were relatively milder for the pulp and paper industries than for the logging and solid wood industries. The annual total world production and trade were less than half of a percent lower without illegal logging than with it (Table 6). This decrease in supply was accompanied by an increase in world prices of 0.5 to 1.5% for pulp, and of less than 1% for paper and paperboard (Table 3).

But, the change in industrial roundwood supply affected strongly the location of production and trade. In developing countries, production was 2 to 4% lower without illegal logging, depending on the initial illegal logging rate, while exports were 8 to 16% lower. Meanwhile, production in developed countries increased and compensated for 70% of the decrease in production in developing countries. The rise in exports of developed countries matched or exceeded the decrease in developing countries.

Without illegal logging, production of pulp and paper decreased the most in China and in Indonesia, regardless of the assumed initial rates of illegal logging. Correspondingly, the imports of China increased, while Indonesia's exports decreased. In Brazil, the magnitude of decrease in production, and the attendant decrease in exports, depended critically on the assumed initial rates of illegal logging. Lesser decreases in production occurred in Finland, the Russian Federation, and the United States.

The largest production gains were in Canada, Germany, and Sweden. In Canada and Sweden the added production went to exports, while in Germany, it substituted for some imports while exports also increased.

3.5. Effects on forest stock

The elimination of illegal logging from 2007 to 2011 increased the global level of growing stock in forests by a relatively small amount (Table 7). Although the increase in forest stock with the high initial illegal logging rates was more than double that with the low rates, it was still less than half of a percent over the projection period. However, the difference between the stock level "with" and "without" illegal logging increased steadily throughout the period.

While without illegal logging the growing stock increased in developing countries, it decreased in developed countries. And, the increase in growing stock in developing countries was two to three times the decrease in developed countries.

The largest decrease in forest stock occurred in the United States and Canada, and to a lesser extent in other countries where illegal logging is currently minimal but where the legal harvest of timber would increase due to the higher price of industrial roundwood. The GFPM ignores possible increases in forest investments with higher prices, which could increase forest stock in the long run, but those effects would be minor within the projected time period.

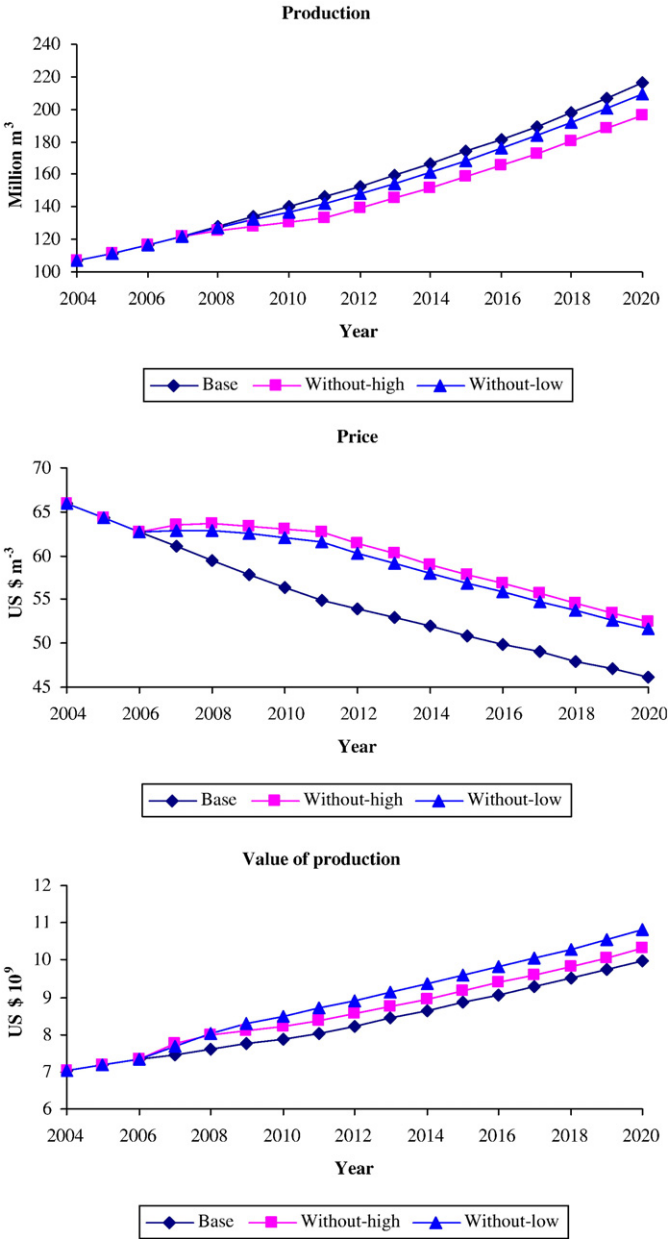

Fig. 2. Predicted production, price, and value of production of industrial roundwood in the Russian Federation in the base scenario, and with a progressive elimination of illegal logging from 2007 to 2011, with high or low assumed rates of illegal logging.

The main increases in forest stock due to the elimination of illegal logging occurred in the Russian Federation, China, Malaysia, and Indonesia, countries in which illegal logging is substantial. In Brazil, the level of the increase in stock depended critically on the assumption regarding the initial rates of illegal logging, reflecting the uncertainty about the true rate (Table 1).

3.6. Effects on revenues, expenditures and value added

Table 8 summarizes the effects of the elimination of illegal logging on producer revenues, consumer expenditures, and value added. Producer revenues are the sum of the value of production of all the 14 products considered in the study, at local prices. Consumer expenditures are the sum of the value of consumption (production plus imports, minus exports), for the same products and prices. Value added is the value of all products, minus the cost of wood or fiber input. Thus, the value added in sawmilling is the value of the sawnwood produced minus the cost of the logs, and the value added in papermaking is the value of the paper minus the cost of the fiber input. The value added in Table 8 is the total value added in all forest industries. Producer revenues, consumer expenditures, and value added are in constant US$, with the purchasing power of 2004.

Fig. 3. Predicted production, price, and value of production of plywood and veneer in Indonesia, in the base scenario, and with a progressive elimination of illegal logging from 2007 to 2011, with high or low assumed rates of illegal logging.

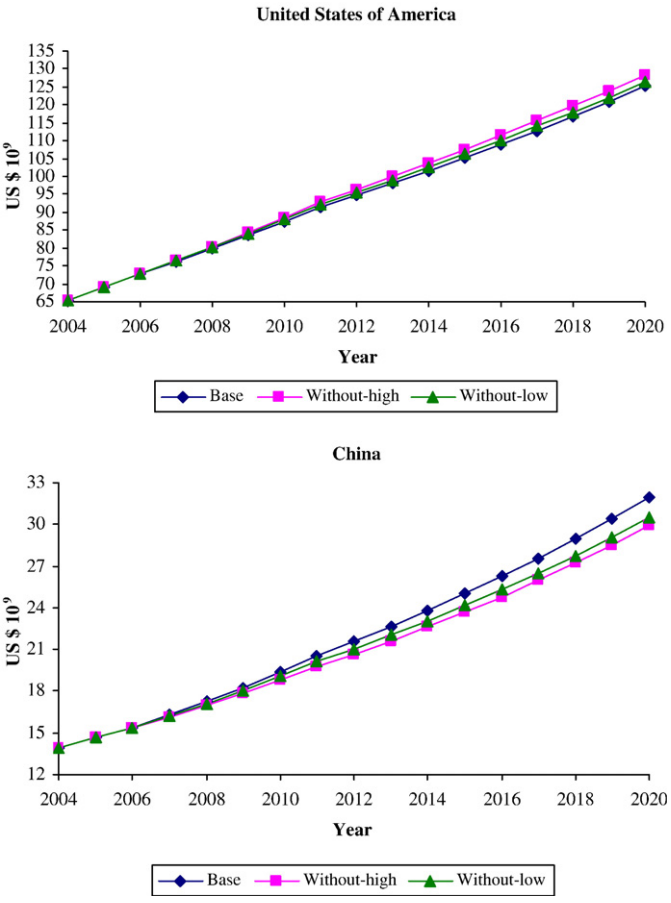

Fig. 4. The progressive elimination of illegal logging from 2007 to 2011 would cause the total value added in forest industries to increase in the United States while it would decrease in China. "Base" refers to the scenario with continued illegal logging. "Without" refers to the progressive elimination of illegal logging, with high or low assumed rates of illegal logging.

At world level, changes in producer revenues are equal to changes in consumer expenditures, except for relatively small changes in transport cost due to the changes in trade. The world producer revenues and consumer expenditures were 1 to 2% higher without illegal logging, depending on the assumed initial illegal logging rates. The predicted global decrease in value added was less than half of a percent.

However, the effects differed substantially by country. For the United States, Canada, and other developed countries the increase in producer revenues much exceeded the increase in consumer expenditures. In contrast, in China and other developing countries the increase in producer revenues was much less than the increase in consumer expenditures. In Japan and the Russian Federation changes in producer revenues were roughly equal to consumer expenditures. In Brazil and Malaysia the changes in producer revenues depended on the assumed initial illegal logging rates.

Although there was little change in value added in the entire forest sector at the global level, there was substantial change in individual countries. With a progressive reduction of illegal logging, value added increased the most (by 2 to 4%) in the United States, Canada, and Germany. The largest decreases in value added were in Indonesia (11 to 12%) and in China (3 to 4%). In Brazil, value added changed little by assuming a low initial illegal logging rate, but decreased by 9% under

the high assumption. In the Russian Federation value added decreased by 1 to 2%.

Fig. 4 shows the predicted trends in value added in the United States and China under the three scenarios. For all scenarios, value added grew faster in the United States. By 2020, annual value added in the United States was approximately $5 billion higher without illegal logging. In contrast, annual value added in China was about $3 billion lower. In both countries, there was little difference in the predicted value added due to the assumed initial rates of illegal logging.

4. Summary and conclusion

Illegal logging is irreconcilable with well-planned and sustainable forest stewardship, as it induces losses of government revenues, deforestation and attendant deterioration of environmental values. Yet, illegal logging is the source of a substantial amount of wood for local industry and for exports, with the attendant employment and income (Prestemon and Laarman, 1989). If costly policies are to be implemented to reduce the rate of illegal logging, it is essential to evaluate their consequences.

This study investigated the effects of a gradual reduction in illegal logging of industrial roundwood. We used the Global Forest Products Model to predict changes in the world forest sector from 2007 to 2020, with and without illegal logging. The specific policy assumed that the harvest of illegally logged industrial roundwood would be reduced progressively from its level in 2007 to a total elimination by 2011. To check the sensitivity of the results to the uncertain current rates of illegal logging, the calculations were repeated with a set of assumed high and low initial rates.

Regardless of the initial logging rates, the impact of the elimination of illegally logged timber led to modest relative changes in forest product prices, production, trade, consumption, and forest stocks at the world level. In particular, world prices increased by 2 to 4% depending on the product.[3] There were however substantial differences in the effects across countries. In general, production in all industries, from logging to pulp and paper, decreased in developing countries. Concurrently, production increased in developed countries, but without totally compensating for the decline in developing countries, and thus causing higher world prices.

As the elimination of illegal logging led to relative price increases greater than the relative decrease in production, the annual total producer revenues and consumer expenditures rose by 2% worldwide. Consumer expenditures increased in all major countries. Producer revenues increased as well, except in Brazil and Malaysia, where they decreased under the assumption of high initial illegal logging rates.

In countries with high illegal logging, or relying heavily on imported roundwood from countries with high illegal logging rates, consumer expenditures rose more than twice as much as producer revenues. The reverse happened in countries which apparently process little illegally logged timber, such as the United States, Canada, Sweden, and New Zealand. There, the increase in producer revenues was double the increase in consumer expenditures.

The effect of eliminating illegal logging on the value added in wood industries was negligible at the world level. However, value added decreased substantially in countries with much illegal logging, such as Indonesia (up to a 12% reduction in value added), or dependent on imported timber, such China (up to a 4% reduction). Conversely, value added increased the most in countries with little illegal logging and efficient wood manufactures (by 4% in Germany and Canada, and by 2% in the United States).

Although total elimination of illegal logging may not be feasible, it could be decreased through concerted action. To that end, the summary numbers presented here, and the details for individual countries and industries, should be useful in deciding whether policies that would progressively reduce illegal logging should be considered. Some countries would clearly be more affected than others, both economically, through effects on producers and consumers, and ecologically, through effects on the forest stock.

Reducing illegal logging could be achieved by a variety of measures, such as expanding wood certification, improving concession management, stepped up enforcement of forest laws, and higher sanctions for violators (McElwee, 2004). Protecting parks and preserves, addressing corruption, clarifying tenure, reducing forest land conversion, and improving information systems would also help (McCarthy, 2002; Smith et al., 2003). But, to be successful, policies should avoid raising the cost of legitimate logging. Otherwise, the cost differential would increase the incentive for illegal operators (Contreras-Hermosilla et al., 2007).

This study has focused on the economic dimension, and found that the losses due to reducing illegal logging are concentrated in developing countries or countries in transition to market economies. These would also be the countries that would benefit from well managed forests, but they would also bear the costs of implementing new policies or enforcement systems unless assisted. Although the magnitude of these losses makes full compensation politically unrealistic, a palliative to the negative impact in some countries would be to strengthen assistance from the countries that would benefit the most commercially from the global elimination of illegal logging, while recognizing that domestic measures are needed to control if not eliminate illegal logging.

Acknowledgments

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Appendix A

The following model deals with two countries (i=1,2), and three products (k=w for wood, k=s for sawnwood, k=a for paper). The experiment consists in observing the changes that follow the elimination of illegal logging in country 2.

Finding the economic equilibrium is equivalent to maximizing the sector social surplus, equal to the sum of the producers' and consumers' surplus (Samuelson, 1952). This surplus is equal to the value of sawnwood and paper to their users (the area under the demand curves), minus the cost of wood supply (the area under the wood supply curves), minus the cost of manufacturing sawnwood and paper beyond the wood cost, minus the transport cost:

$$\max Z = \sum_{i,k=s,a} \int_0^{D_{ik}} (\alpha_{ik} + \beta_{ik} D_{ik}) \mathrm{d}D_{ik} - \sum_i \int_0^{Y_{iw}} (\gamma_{iw} + \delta_{iw} Y_{iw}) \mathrm{d}Y_{iw} - \sum_{i,k=s,a} \int_0^{Yi_k} (\varepsilon_{ik} + \phi_{ik} Y_k) \mathrm{d}Y_{ik} - \sum_{i,k=s,a} \varphi_{ik} I_{ik}$$

where D is consumption, Y is production, I is quantity traded, and α, β, γ, δ, ϕ, φ are parameters.

[3] This is smaller than the world price change predicted in an earlier study (Seneca Creek Associates 2004), although the predictions for prices in the United States are similar in both studies, and also in the 2 to 4 percent range. Both studies were done with the GFPM. A possible explanation for the difference in world prices is that the GFPM used here predicts shifts in timber supply endogenously. In the earlier version, the exogenous supply shifts implied lower production and higher real prices than obtained with the endogenous timber supply (Turner et al. 2006a).

The wood balance constraints express the fact that in each country, the wood imported plus the domestic supply must equal the wood used in manufacturing sawnwood and paper plus the wood exports:

$$I_{iw} + Y_{iw} - \sum_{k=s,a} \mu_{iwk} Y_{ik} - X_{iw} = 0 \quad \text{for } i = 1,2$$

The end product balance constraints state that imports of sawnwood or paper plus domestic production equal domestic demand plus exports:

$$I_{ik} + Y_{ik} - X_{ik} = 0 \quad \text{for } i = 1,2;\ k = s,a$$

The world trade constraints balance world imports and exports:

$$I_{1k} + I_{2k} - X_{1k} - X_{2k} = 0 \quad \text{for } k = w,s,a$$

At the optimum, the shadow prices of the material balance constraints give the market equilibrium price of each product in each country. For a net importing country, the price is equal to the price in the exporting country plus the transport cost. For a net exporting country the price is equal to the world price (the shadow price of the world trade constraints). The price of sawnwood or paper in a country is equal to the price of the wood used in making them plus the manufacturing cost.

The following parameters were used to calculate the initial equilibrium before the shift in supply due to the curtailing of illegal logging:

Sawnwood demand: $\alpha_{1s} = 700$, $\beta_{1s} = -20$, $\alpha_{2s} = 600$, $\beta_{2s} = -15$
Paper demand: $\alpha_{1a} = 1200$, $\beta_{1a} = -15$, $\alpha_{2a} = 1200$, $\beta_{2a} = -16$
Wood supply: $\gamma_{1w} = 10$, $\delta_{1w} = 3$, $\gamma_{2w} = 50$, $\delta_{1w} = 3$
Sawnwood manufacturing cost: $\varepsilon_{1s} = 45$, $\phi_{1s} = 0.1$, $\varepsilon_{2s} = 30$, $\phi_{2s} = 0.1$
Wood per unit of sawnwood: $\mu_{1ws} = 1.5$, $\mu_{2ws} = 2$
Wood per unit of paper: $\mu_{1wa} = \mu_{2wa} = 3$
Paper manufacturing cost: $\varepsilon_{1a} = 25$, $\phi_{1s} = 0.1$, $\varepsilon_{2s} = 15$, $\phi_{2s} = 0.1$
Transport cost: $\varphi_{1s} = \varphi_{2s} = \varphi_{1a} = \varphi_{2a} = 5$

With these parameters, the solution of the above quadratic programming problem gives the following market equilibrium before the shift in supply:

End demand:

In country 1: $D_{1s} = 11.9$, $D_{1a} = 22.9$
In country 2: $D_{2s} = 8.93$, $D_{2a} = 21.7$

Production:

In country 1: $Y_{1w} = 88.9$, $Y_{1s} = 20.8$, $Y_{1a} = 19.3$
In country 2: $Y_{2w} = 76.1$, $Y_{2s} = 0.0$, $Y_{2a} = 25.4$

Trade:

In country 1: $X_{1s} = 8.9$, $I_{1a} = 3.6$
In country 2: $I_{2s} = 8.9$, $X_{2a} = 3.6$

Price:

In country 1: $P_{1w} = 276.7$, $P_{1s} = 462.1$, $P_{1a} = 857.0$
In country 2: $P_{2w} = 278.2$, $P_{2s} = 467.1$, $P_{2a} = 852.0$

This solution verifies the properties of economic equilibrium. In addition to the material balance, the price in importing countries is equal to the price in the exporting country plus the transport cost. Furthermore, the local price of sawnwood and paper is equal to the cost of the wood input plus the marginal manufacturing cost.

The curtailment of illegal logging in country 2 shifts its wood supply to the left. This is simulated by changing the intercept of the inverse wood supply equation from γ_{2w}=50 to γ_{2w}=100. The quadratic programming problem solved with this new configuration leads to the following changes in equilibrium:

End demand:

In country 1: $\Delta D_{1s} = -1.4$, $\Delta D_{1a} = 1.6$
In country 2: $\Delta D_{2s} = -0.8$, $\Delta D_{2a} = -1.5$

Production:

In country 1: $\Delta Y_{1w} = 2.6$, $\Delta Y_{1s} = -1.4$, $\Delta Y_{1a} = 1.6$,
In country 2: $\Delta Y_{2w} = -14.0$, $\Delta Y_{2s} = 0.0$, $\Delta Y_{2a} = -4.7$

Trade:

In country 1: $\Delta X_{1s} = -0.8$, $\Delta I_{1a} = -3.2$
In country 2: $\Delta I_{2s} = -0.8$, $\Delta I_{2a} = -3.2$

Price:

In country 1: $\Delta P_{1w} = 7.9$, $\Delta P_{1s} = 11.74$, $\Delta P_{1a} = 23.9$,
In country 2: $\Delta P_{2w} = 8.1$, $\Delta P_{2s} = 11.7$, $\Delta P_{2a} = 23.9$

Part of the decrease in wood production in country 2 is compensated by an increase in country 1. Nevertheless, prices increase for all products in both countries. As a result, the demand for sawnwood and paper decreases in both countries. The change in production is more varied. In particular, in country 1, sawnwood production decreases while paper production increases. This phenomenon is also observed in the full model with all countries and products where a decrease in sawnwood production may occur simultaneously with an increase in production in wood based panels and pulp and paper, in the context of higher prices for all products.

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