ESTIMATING INTERNATIONAL WOOD AND FIBER UTILIZATION ACCOUNTS IN THE PRESENCE OF MEASUREMENT ERRORS

JOSEPH BUONGIORNO, CHIA-SHENG LIU, AND JAMES TURNER*

ABSTRACT

Estimates of the amounts of wood and fiber used by various industries, and the corresponding input-output coefficients, are needed for international forest sector analysis and forecasting. Yet, only the data on total national production and trade are usually known and the production data are often inaccurate. The method proposed here builds wood and fiber utilization accounts, based on the reported data and on prior knowledge of consumption functions and of production techniques. The method first estimates the consumption of final products in countries with obvious errors or missing data, based on empirical functions linking consumption to GDP per capita. Next, a goal-programming model is used to estimate the production data by minimizing the difference between the estimated and the reported production, while keeping input-output coefficients near their prior value, and within plausible bounds. The results give estimates of the wood and other fiber utilization accounts by country, and of the corresponding input-output coefficients. The method was applied to the data from 180 countries for the year 1996. The results showed that the reported production data of several countries must be adjusted to be consistent with prior knowledge of consumption functions and of techniques of production.

Keywords: Consumption function, data estimation, demand, goal programming, input-output, sector analysis, supply, trade.

"The art of navigation is to know where you are."
Alf Leslie

~

INTRODUCTION

Data accuracy is the cornerstone of forest sector modeling. Lack of good comparable data causes real difficulty in developing multi-country models. International forest sector data are often inaccurate due to weak surveying methods and accounting systems, and inevitable human errors. Sometimes, the data are totally missing.

* Joseph Buongiorno, Chia-sheng Liu, and James Turner, Department of Forest Ecology and Management, 1630 Linden Drive, Madison, WI 53706, USA, E-mail: jbuongio@facstaff.wisc.edu.Phone: (608) 262-0091, Fax: (608) 262-9922.

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Poor and missing data are pervasive among low-income countries, but also occur in rich countries. It is not uncommon to find countries where, for some products and years the data on production, imports and exports imply negative consumption. Further, there are many, and sometimes-large, inconsistencies in several countries between data on raw material input and product output, for example between the data on pulp consumption and the data on paper production.

Like navigation, which demands accurate knowledge of the ship position, good prediction of the world forest sector requires solid data on its current state. While negative consumption of a product is easy to detect, it is not easy to fix without introducing disagreements with other data. Furthermore, other inconsistencies, such as between pulp consumption and paper production are more difficult to find and to correct.

The problem of data inaccuracy is critical in input-output (I-O) analysis. Input-output coefficients describe how much wood and other fibers are used to make a variety of products in different countries, for example, how much industrial roundwood is used per unit of sawnwood in India. These I-O coefficients are parameters in models of the world forest sector (e.g. FAO, 1997). They describe the technology and the efficiency of resource utilization in wood processing, mill recovery, and recycling (Baker & Yeager, 1974; Tiemann, 1944; Zhang *et al.*, 1996). I-O coefficients are used commonly to describe demand and supply of wood products with "techno-metric" models in which some of the demand-supply relations are represented by econometric functions, and others by activity analysis (Kallio *et al.*, 1987). In the Global Forest Products Model (GFPM), the I-O coefficients in different countries determine in part the levels of consumption, production, and trade (Zhu *et al.*, 1998).

Yet, I-O data are usually not available. At best, the total amount of wood and fiber consumed are known, but rarely their distribution by product. In past studies, I-O coefficients and missing or erroneous data have been estimated and rectified by experts' judgment, as in the first version of the GFPM model (FAO, 1997). However, experts' judgments are typically not documented and they are hard to replicate.

The purpose of this paper is to present a method to estimate I-O coefficients and improve the quality of the data, using all available information in systematic, objective, and replicable fashion. The method uses both "hard" data (official statistics in publications or databases) and "soft" data such as expert knowledge of techniques of production (Forrester, 1980). The specific data we seek to verify and improve are:

a. Data on production of all main forest products, and

b. wood and fiber utilization accounts, and related I-O coefficients concerning the use of raw materials in various industries, in particular for the transformations of industrial roundwood to solid wood and pulp products, and then from pulps and other fibers to paper and paperboard.

METHOD

Figure 1 shows the material flow simulated by the GFPM model in each country. The GFPM projects production, imports, exports, and prices of each product. The GFPM has econometric equations that represent the supply of raw materials and the demand for end products. Activity analysis represents the transformation of industrial roundwood into sawnwood, panels, and pulps; and the manufacture of

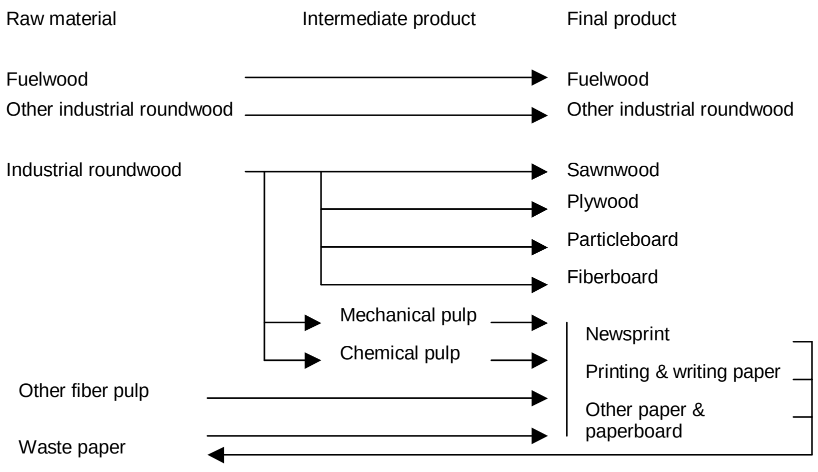

FIGURE 1. WITHIN-COUNTRY MATERIAL FLOWS IN THE GFPM MODEL.

wood pulps and other fibers (including waste paper) into paper and paperboard. This requires knowledge of I-O coefficients for each stage of manufacturing. Typically these data are not available for most countries, and often the production data are inaccurate.

The method to estimate the I-O coefficients and improve the production data has two steps. First, estimate consumption and production of final products where data are missing or have obvious errors. Second, estimate input-output coefficients while adjusting the reported production data (and the production data estimated in the first step) if necessary.

The method assumes throughout that the trade volumes (imports and exports) are correct. This is not always the case (Durst *et al.*, 1986; Luppold & Thomas, 1991). However, the trade data, though imperfect, tend to be much more accurate than the production data. In many countries, production data are often just rough office estimates of statistical agencies, or based on casual company reports. Instead, imports and exports go through the customs agencies, which tend to keep better (though admittedly imperfect) records.

Improving Final Product Data

The first step deals with countries that have missing or implausible data for final products, such as negative consumption. The final products are fuelwood, other industrial roundwood (such as poles, piling, and posts), sawnwood, wood-based panels, and paper and paper-board (Figure 1).

There are systematic relations between the wealth of a country and the consumption of wood products (Gregory, 1966; Buongiorno & Grosenick, 1977; Simangunsong & Buongiorno, 2001). The richer a country is, the more wood products it tends to consume (except for fuelwood, and possibly other industrial roundwood, for which the relation is negative). Therefore, the GDP per capita, a common index of the wealth of a country, may be used to estimate per capita consumption of wood products. Other factors, especially prices, also affect consumption (Buongiorno, 1978; Baudin & Lundberg, 1987), however the price differences between countries are small compared to the GDP differences, and prices are even less known than quantities in countries where consumption must be estimated. Here, consumption was predicted from GDP and population only.

Estimation of Final Product Consumption

The assumption is that consumption per thousand capita and GDP per capita are related as follows:

$$\ln c_{ij} = a_i \ln y_j + b_i + u_{ij}, \tag{1}$$

where i refers to a product, j to a country, c_{ij} is consumption per capita of product i in country j, y_j is gross domestic product (GDP) per capita of country j in US \$, and u_{ij} is the residual error.

The method consists in estimating the parameters a_i and b_i by regression, with data from many countries in a particular year, preferably the year for which consumption is to be estimated. For countries with negative reported consumption, the estimated (expected) consumption per capita at a given y_j is:

$$\overline{c}_{ij} = \exp(\hat{a}_i \ln y_j + \hat{b}_i) \tag{2}$$

High and low estimates of consumption per capita are also given by:

$$C_{ij}^{U,L} = \exp\left[\hat{a}_i \ln y_j + \hat{b}_i \pm tS_i \left(1 + 1/n_i + \frac{\left(\ln y_j - \overline{\ln y_j}\right)^2}{\sum_j \left(\ln y_j - \overline{\ln y_j}\right)^2}\right)^{1/2}\right], \tag{3}$$

where t is the Student t ratio for the number of countries and desired probability level, S_i is the mean square of the residuals in the regression (1), and n_i is the number of observations for product i. For example, to get a 95% confidence interval of expected consumption at a given GDP level we set $t \approx 2$ for 100 observations (Maddala, 1977, pp.82, 507).

This method can also be used to estimate consumption where it is non-negative, but too low. Indeed, few countries should have zero consumption of any product, and Equations (2) or (3) can then be used to estimate true consumption. In this way, data that are correct may be revised incorrectly, but this should happen no more than 5% of the time. The estimate of total national consumption, C_{ij}, is then the product of the estimated consumption per capita by the country population for the year of interest.

If consumption of a final product is estimated from GDP, production is derived from consumption, assuming that the trade data are correct, and recognizing that production cannot be negative:

$$P_{ij} = \max\left(0, C_{ij} + e_{ij} - i_{ij}\right), \tag{4}$$

where P_{ij} = estimated production, C_{ij} = estimated consumption; e_{ij}, i_{ij} = reported exports and imports, respectively.

For fuelwood and "other industrial roundwood", which are raw materials as well as final products (Figure 1), the method ends with Equation (4). For other products, the second step aims at determining how wood and other fiber are used in making final products, such as sawnwood, or in making first an intermediate product (e.g. chemical pulp), and then a final product, such as newsprint. In that second step, the first estimate of production given by (4) may be revised in light of other data.

Estimating I-O Coefficients and Production Data

This second step of the method estimates the wood and fiber utilization accounts for each country, and the corresponding input-output coefficients. Simultaneously, the production data are adjusted if necessary. The objective is to obtain input-output coefficients that require the least adjustment of the reported production data, while staying near prior knowledge of the technology (e.g. as held by experts). The solution technique is goal programming.

The method uses production data either reported or estimated from Equation (4), reported import and export data, and prior I-O coefficients and other constraints based on expert knowledge.

The equations follow the material flow in Figure 1, which shows that industrial roundwood (*Round*) is the input for mechanical pulp (*Mech*), chemical pulp (*Chem*), sawnwood (*Sawn*), plywood (*Ply)*, particleboard (*Part*), and fiberboard (*Fib*). Then, mechanical pulp and chemical pulp together with other fiber pulp (*Ofib*), and waste paper (*Waste*) are inputs in newsprint (*News*), printing and writing paper (*Print*), and other paper and paperboard (*Opap*). The final products are sawnwood, plywood, particleboard, fiberboard, newsprint, printing and writing paper, and other paper and paperboard.

The model equations (Table 1), and the variables and parameters (Table 2) refer to one country and one year. Lower-case letters are either reported data, production data estimated in the first step, or prior estimates of I-O coefficients and other constants. Upper-case letters are choice variables, all nonnegative, or variables that depend on the choice variables.

The first term of the objective function (5) contains the sum of the absolute deviations of the estimated from the reported production, weighted by the price of the products. The second term contains the sum of the absolute value of the deviations of estimated inputs from inputs implied by prior input-output coefficients, weighted by the geometric mean of the price of the input and output. The underlying assumption is that the data, be they official statistics or technical knowledge, tend to be more accurate for more valuable products.

The parameter $0 \leq \beta \leq 1$ marks the relative importance of getting estimates near the reported data or near the amounts implied by the prior I-O coefficients. At one extreme, $\beta = 0$ would mean that estimated production should be consistent with the expected prior I-O coefficients, independently of the reported production. At the other extreme, $\beta = 1$ would mean that estimated production should be as close as possible to the reported, subject to the prior bounds on the I-O coefficients.

Adjusting the choice variables subject to the constraints minimizes this objective function.

Equation (6) estimates the productions of each input as the sum of the estimates of that input in all outputs, plus net trade (assumed to be known exactly).

TABLE 1. GOAL-PROGRAMMING MODEL TO ESTIMATE WOOD AND FIBER UTILIZATION.

Objective function:

$$\min Z = \beta \sum_{x \in I \cup O} \left(P_x^+ + P_x^-\right) w_x + (1-\beta) \sum_{m \in I} \sum_{n \in O} \left(C_{mn}^+ + C_{mn}^-\right) w_{mn} \tag{5}$$

Estimated production of inputs:

$$P_m = \sum_{n \in O} C_{mn} + e_m - i_m, \qquad m \in I \tag{6}$$

Expected input m in product n:

$$\bar{C}_{mn} = \bar{a}_{mn} P_n, \qquad m \in I, n \in O \tag{7}$$

$$\bar{a} = \frac{1}{2}\left(a_{mn}^L + a_{mn}^U\right)$$

Deviation of estimated from reported production:

$$P_x - p_x + P_x^- - P_x^+ = 0, \qquad x \in I \cup O \tag{8}$$

Deviation of estimated from expected input:

$$C_{mn} - \bar{C}_{mn} + C_{mn}^- - C_{mn}^+ = 0 \qquad m \in I, n \in O \tag{9}$$

Feasible range of input m for output n:

$$P_n a_{mn}^L \le C_{mn} \le P_n a_{mn}^U, \qquad m \in I, n \in O \tag{10}$$

Feasible range of total inputs for output n:

$$P_n a_n^L \le \sum_{m \in I} C_{mn} \le P_n a_n^U, \qquad n \in O \tag{11}$$

Feasible post-consumer recovery:

$$\left(C_{News} + C_{Print} + C_{Oher}\right) r^L \le P_{waste} \le \left(C_{News} + C_{Print} + C_{Other}\right) r^U \tag{12}$$

Implicit input-output coefficients:

$$a_{mn} = \frac{C_{mn}}{P_n}, \qquad m \in I, n \in O \tag{13}$$

Equation (7) computes the expected input for a given output. It assumes that the prior I-O coefficients are random variables distributed symmetrically between a lower and upper bound, so that the expected value of each prior I-O coefficient is equal to the average of its bounds.

Equation (8) defines the deviation of estimated production from reported production p_x, which may itself have been estimated from Equation (4).

Equation (9) defines the deviation of estimated input from the expected input implied by the prior input-output coefficient.

TABLE 2. VARIABLES AND PARAMETERS USED IN THE GOAL-PROGRAMMING MODEL.

Sets and input data:	
I:	set of inputs {*Round, Mech, Chem, Ofib, Waste*}[1].
O:	set of outputs {*Mech, Chem, Sawn, Ply, Part, Fib, News, Print, Opap*}[1].
β:	weight of official data vs. prior input-output data.
w_x:	price of product x.
w_{mn}:	geometric mean of the price of input m and output n.
p_x, i_x, e_x:	reported data on production, imports, and exports.
a_{mn}^L, a_{mn}^U :	lower, upper bound on prior input-output coefficient.
a_n^L, a_n^U :	lower, upper bound on prior total input per unit of output n.
r^L, r^U :	lower, upper bound on prior post-consumer recovery rate.
Choice variables, all non-negative:	
P_n:	estimated production of output n.
P_x^+ :	estimated production above reported production of product x.
P_x^- :	estimated production below reported production of product x.
C_{mn}:	estimated input m in output n.
C_{mn}^+:	estimated input above input implied by prior input-output coefficients.
C_{mn}^-:	estimated input below input implied by prior input-output coefficients.
Other variables:	
P_m:	estimated production of input m.
$\bar{C}_{mn}$:	expected input m in output n, with average prior input-output coefficients.

[1] *Defined in Table 3.*

Constraint (10) insures that the input going to a product, say mechanical pulp to newsprint, is within the range of the prior input-output coefficient defined by experts.

Equation (11) is similar to Equation (10), but the bounds apply to the total amount of different inputs going into a product, such as the mechanical and chemical pulp going to newsprint.

Constraint (12) keeps the production of waste paper within bounds based on prior knowledge of the post-consumer recovery rate in a country.

The model in Table 1 has the structure of a goal-programming problem, with the objective of minimizing the sum of the weighted deviations from the goals. Since the objective function and the constraints are all linear in the choice variables, the best solution can be found with a linear-programming algorithm such as the simplex method (Dantzig, 1963). The solution gives estimates of production, P_x, for all inputs and outputs, and estimates of the amount of input going into each intermediate or final output, C_{mn}. Then, each implicit input-output coefficient (amount of input per unit of output) is derived by Equation (13).

DATA AND PARAMETERS

The method was applied to estimate input-output coefficients and related data for the year 1996, in 180 countries. The source of the international data on forest products and population was the Food and Agriculture Organization (FAO) of the United Nations. The data were obtained from their online FAOSTAT database (FAO, 1999a). The product groups used by the GFPM model and in this study are listed in Table 3. Detailed definitions are available in the FAO Yearbook, Forest Products (e.g. FAO, 1999b). The data on GDP came from the World Bank CD-ROM, 1997.

The upper bounds and lower bounds of the prior input-output coefficients, and the bounds on the recovery rates of paper, were based on the coefficients estimated for each country by a group of experts for a previous study (Zhu *et al.*, 1998). The countries were divided into high-income and low-income groups according to FAO (1997). Then, for the high-income countries we assumed that each I-O coefficient could be no less than the smallest I-O coefficient estimated by experts, and no more than the largest. We did the same for low-income countries.

The resulting bounds are in Table 4. For the I-O coefficients involving industrial roundwood, the bounds suggested that wood utilization was in general less efficient in low income than in high income countries (both the lower bound and the upper bound were higher in low-income countries). For the transformation of wood pulp and other

TABLE 3. PRODUCTS IN THE GLOBAL FOREST PRODUCTS MODEL (GFPM).

SITC Code	Product name	Abbreviation	Unit	Demand	Supply
245	Fuelwood and Charcoal		10^3 m^3	E[1]	E
246/247	Sawlogs and Pulpwood	*Round*	10^3 m^3	I[2]	E
	Other Industrial roundwood		10^3 m^3	E	E
248	Sawnwood	*Sawn*	10^3 m^3	E	I
634.1,634.3/4	Veneer & Plywood	*Ply*	10^3 m^3	E	I
634.2	Particleboard	*Part*	10^3 m^3	E	I
634.5	Fiberboard	*Fiber*	10^3 m^3	E	I
251.2	Mechanical Wood Pulp	*Mech*	10^3 t	I	I
251.91,.61,.62 ,3,.4,.5	Chemical & Semi-Chemical Wood Pulp	*Chem*	10^3 t	I	I
251.92	Other Fiber Pulp	*Ofib*	10^3 t	I	E
251.1	Waste Paper	*Waste*	10^3 t	E	I
61.1	Newsprint	*News*	10^3 t	E	I
641.2/3	Printing and Writing Paper	*Print*	10^3 t	E	I
Ex641	Other Paper and Paperboard	*Opap*	10^3 t	E	I

[1] *Demand or supply is represented in the GFPM with an econometric equation.*
[2] *Demand or supply is represented in the GFPM with input-output coefficients.*

fibers to paper and paperboard, the only strong difference between low-income and high-income countries was the much greater possible use of other fiber pulp (from straw, bagasse, etc...) in low-income countries.

The data for the vectors w_x and w_{mn} to weight the deviations of the estimated production from reported production, and of the estimated input from the prior input, were the average prices of world imports in 1996, by product (Table 5).

The coefficient β in the objective function (5) was set at 0.9. This gave major importance to obtaining production estimates near the official data. Less weight (0.1) was given to keeping the input-output coefficients near their expected

TABLE 4. PRIOR LOWER AND UPPER BOUND FOR INPUT-OUTPUT COEFFICIENTS.

		I-O Coefficient			
		High Income Countries[a]		Low Income Countries[b]	
Input	Output	Min	Max	Min	Max
		m^3m^{-3}			
Industrial Roundwood	Sawnwood	1.15	2.30	1.46	2.40
	Plywood	1.42	3.80	1.65	5.00
	Particleboard	1.25	2.21	1.32	2.35
	Fiberboard	1.04	2.11	1.50	2.53
		m^3t^{-1}			
	Mechanical pulp	1.50	3.10	2.12	3.20
	Chemical pulp	2.50	4.50	2.50	4.72
		tt^{-1}			
Mechanical Wood Pulp	Newsprint	0.05	0.70	0.00	0.59
	Printing & writing paper	0.01	0.42	0.00	0.67
	Other paper & paperboard	0.01	0.90	0.00	0.45
Chemical Wood Pulp	Newsprint	0.09	0.62	0.02	0.70
	Printing & writing paper	0.09	0.67	0.00	1.00
	Other paper & paperboard	0.07	0.58	0.00	1.00
Other Fiber Pulp	Newsprint	0.00	0.08	0.00	0.60
	Printing & writing paper	0.00	0.09	0.00	0.90
	Other paper & paperboard	0.00	0.20	0.00	0.85
Waste Paper	Newsprint	0.00	0.70	0.00	0.76
	Printing & writing paper	0.02	0.88	0.00	0.60
	Other paper & paperboard	0.05	1.00	0.00	1.00
Total Fiber	Newsprint	1.00	1.10	1.10	1.10
	Printing & writing paper	0.90	1.00	1.00	1.00
	Other paper & paperboard	1.00	1.03	1.03	1.03

[a] *Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Israel, Italy, Japan, Kuwait, Luxembourg, Netherlands, Norway, New Zealand, South Africa, Spain, Sweden, Switzerland, U.K., U.S.A.*

[b] *Rest of the world.*

TABLE 5. PRICES USED TO WEIGHT DEVIATIONS OF ESTIMATED FROM OBSERVED DATA.

Product	Unit	Price[1] (US$ unit^{-1})
Industrial roundwood	m^3	105
Mechanical wood pulp	t	367
Chemical wood pulp	t	489
Other fiber pulp	t	828
Waste paper	t	134
Sawnwood	m^3	222
Plywood	m^3	453
Particle Board	m^3	241
Fiber Board	m^3	346
Newsprint	t	650
Printing & Writing Paper	t	1035
Other Paper & paperboard	t	1133

[1] *Unit value of world imports (FAO, 1999).*

prior value. They could vary relatively freely, as long as they stayed within their prior upper and lower bounds.

The upper bound for the waste paper recovery rate, r^U, was set at 60%. In 1994 the highest recovery rates were 51% in Japan and 59% in Germany (FAO, 1997).

RESULTS

Estimates of Final Product Consumption

The regression equations used to estimate final product consumption are in Table 6. Consumption per capita of fuelwood was found to be significantly lower in high income countries, as expected. Consumption per capita of other industrial roundwood (poles, piling and posts) was independent of income. For all other products, consumption per capita increased with GDP per capita. For sawnwood, the elasticity of consumption with respect to GDP was less than unity. For panels and paper, all the elas-

TABLE 6. CONSUMPTION FUNCTIONS FOR FINAL PRODUCTS[a].

	Coefficient					ln(y_i)	
Commodity	Intercept	ln(y_i)	R^2	S_i^d	n_i^b	Mean	Variance
Fuelwood	8.57 ** (0.79) [c]	−0.47 ** (0.10)	0.13	1.92	144	7.63	2.47
Other industrial roundwood	3.39 ** (0.70)	−0.07 (0.09)	0.00	1.55	113	7.53	2.57
Sawnwood + sleepers	−3.27 ** (0.56)	0.85 ** (0.07)	0.47	1.42	155	7.65	2.51
Plywood + veneer sheets	−7.81 ** (0.61)	1.17 ** (0.08)	0.61	1.44	143	7.64	2.32
Particleboard	−9.82 ** (0.90)	1.34 ** (0.11)	0.54	1.93	119	7.83	2.46
Fiberboard	−10.04 ** (0.72)	1.28 ** (0.09)	0.61	1.57	126	7.77	2.40
Newsprint	−8.75 ** (0.58)	1.18 ** (0.07)	0.67	1.28	130	7.83	2.40
Printing & writing paper	−9.67 ** (0.59)	1.35 ** (0.07)	0.73	1.27	121	7.75	2.37
Other paper & paperboard	−8.95 ** (0.65)	1.36 ** (0.08)	0.66	1.54	141	7.65	2.45

[a] *The dependent variable is the logarithm of consumption per 1000 capita and y is GDP per capita in $US, in 1996.*
[b] *Number of countries varies by product due to missing data on consumption.*
[c] *Standard error of coefficient.*
[d] *Mean square error of residuals.*
*** Coefficient significantly different from zero at 0.01 level.*

ticity parameters were larger than one, so that a difference in consumption larger than 1% corresponded to a 1% difference in GDP.

The R^2 show that there was much variation around the regression line, especially for the three first products (see also Figure 2). It is well known that other variables besides GDP influence consumption. Experiments with forest stock as an additional variable improved the fit very little. And since the forest stock is also unlikely to be accurate in countries where other production data are wrong or missing, it was not used as a predictor.

The following is a simple example of application of the consumption function to estimate missing production data:

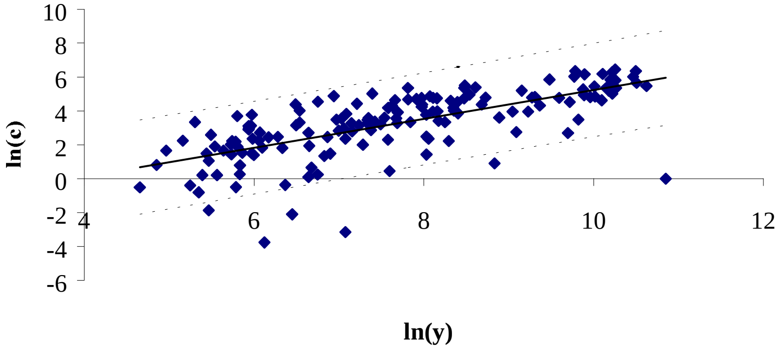

FIGURE 2. REGRESSION OF SAWNWOOD CONSUMPTION PER CAPITA ON GROSS DOMESTIC PRODUCT PER CAPITA (—), WITH 95% CONFIDENCE INTERVAL OF ACTUAL CONSUMPTION CONDITIONAL ON GROSS DOMESTIC PRODUCT (---).

Year: 1996

Country: Ukraine

Reported population: 51,921,000

Reported GDP per capita: 1735 $US

Product: Sawnwood

Reported export: 203000 m^3

Reported import: 167000 m^3

Reported production: N/A

Equation (3), with the coefficients in Table 6 gave the following 95% lower bound for sawnwood consumption per 1000 capita:

$$c_S^L = 18.86 \text{ m}^3$$

Thus, a conservative estimate of total consumption was:

$$C_S = 18.86 \times 51921 = 979489 \text{ m}^3,$$

and, the corresponding estimate of sawnwood production in Ukraine in 1996 was, given the import and export data for the Ukraine (Equation (4)):

$$979489 + 203000 - 167000 = 1015489 \text{ m}^3.$$

This preliminary estimate was then refined in the second step with the goal-programming model, based on the other data for the Ukrainian forest sector, and the prior I-O coefficients in Table 4. Similar estimates were made for 180 countries, for final products exhibiting negative or zero consumption.

Estimates of Utilization Data and I-O Coefficients

The second step, the optimization giving the I-O coefficients and attendant data on wood and fiber utilization was solved for each country in 1996, using the production data estimated in the first step where needed.

For example, Table 7 shows the results for the United States. On the output side, the estimated production of sawnwood, panels, pulp, and paper and paperboard was identical to the reported production. For the input data, the estimated total consumption of industrial roundwood was equal to the reported consumption. For all pulps, estimated consumption was also the same as reported. Only for waste paper was reported consumption slightly smaller than the estimated, but the difference was negligible given the accuracy of the data.

Table 7 also shows estimates of how much wood and fibers were used in each product, for which no data were readily available. For example, the results suggest that in the United States, in 1996, more industrial roundwood went into the production of chemical wood pulp than in the production of sawnwood, while half as much wood went into particleboard as into plywood.

The estimated I-O coefficients for the transformation of industrial roundwood tended to be in the lower range of the prior I-O coefficients for the high-income countries (Table 4). This is in agreement with the notion that wood utilization is relatively efficient in the United States. Similarly, the estimated I-O coefficients for the transformation of total fiber to paper and paperboard were all at their lower bounds (compare the last rows of Table 7 and Table 4), suggesting also a high technical efficiency in papermaking.

The detailed input-output coefficients by fiber and paper product suggest how the fiber mix differs by product. For example, printing and writing paper uses more chemical wood pulp per ton than waste paper, compared to either newsprint or other paper and paperboard.

TABLE 7. WOOD AND FIBER UTILIZATION ACCOUNTS FOR THE UNITED STATES IN 1996.

Input			Output			Estimated
Product	Reported	Estimated	Product	Reported	Estimated	I-O coef.
Industrial roundwood						
	10^3m^3			10^3m^3		m^3m^{-3}
	N/A	126 102	Sawnwood	109 654	109 654	1.15
	N/A	40 423	Plywood	16 975	16 975	2.38
	N/A	19 981	Particleboard	15 985	15 985	1.25
	N/A	6 672	Fiberboard	6 415	6 415	1.04
				10^3t		m^3t^{-1}
	N/A	8 054	Mechanical wood pulp	5 369	5 369	1.50
	N/A	172 729	Chemical wood pulp	49 351	49 351	3.50
Total	373 960	373 960				
Mechanical wood pulp						
	10^3t					tt^{-1}
	N/A	315	Newsprint	6 303	6 303	0.05
	N/A	226	Printing & writing paper	22 553	22 553	0.01
	N/A	4 796	Other paper & paperboard	53 115	53 115	0.09
Total	5 337	5 337				
Chemical wood pulp						
	N/A	3 908	Newsprint			0.62
	N/A	1 511	Printing & writing paper			0.67
	N/A	29 373	Other paper & paperboard			0.55
Total	48 391	48 391				
Other fiber pulp						
	N/A	0	Newsprint			0.00
	N/A	0	Printing & writing paper			0.00
	N/A	168	Other paper & paperboard			0.00
Total	168	168				
Waste paper						
	N/A	2 080	Newsprint			0.33
	N/A	4 962	Printing & writing paper			0.22
	N/A	18 778	Other paper & paperboard			0.35
Total	25 688	25 820				
Total fiber						
	N/A	6 303	Newsprint			1.00
	N/A	20 298	Printing & writing paper			0.90
	N/A	53 115	Other paper & paperboard			1.00
Total	79 584	79 716				

Note: Numbers may not add up due to round-off errors.

Table 8 shows the wood utilization accounts for the Ukraine. On the output side, the estimated production was equal to that reported for all the products for which the data were available. More interestingly, however, sawnwood production, which was not available for the Ukraine, was estimated at $2.1 \times 10^6 m^3$ by the present method. Note that this final estimate was much higher than the preliminary estimate obtained above with the consumption function alone. The final estimate takes into account the data on industrial roundwood production reported by the Ukraine, together with the data on other products.

For the input data, the estimated total consumption of industrial roundwood was equal to the reported consumption. For all the pulps, estimated consumption was also the same as reported. For waste paper estimated consumption was 10% less than reported.

In contrast with the United States, the estimated I-O coefficients for the transformation of industrial roundwood tended to be in the upper range of the prior I-O coefficients for the high-income countries (Table 4). Similarly, the estimated I-O coefficients for the transformation of total fiber to paper and paperboard were all at their upper bounds (compare the last rows of Table 8 and Table 4). Both results suggest a low efficiency of wood and fiber utilization in the Ukraine.

Comparison of the detailed I-O coefficients for fiber input into paper and paperboard suggests that the techniques used in the Ukraine rely much more heavily on recycled fibers than in the United States.

Table 9 summarizes the effect of the adjustments on the total production data by major world regions. For the world total, the relative difference between estimated and reported production was generally small, except for mechanical pulp where estimated world production was 10% larger than the observed. The major source of this discrepancy was in Europe and the former USSR, where the estimated production was 28% larger than the observed. There were also large relative differences in Africa, for mechanical pulp, sawnwood, and newsprint. This suggests that the relative differences may be quite large for some countries of Africa, although the absolute differences are small relative to world production.

TABLE 8. WOOD AND FIBER UTILIZATION ACCOUNTS FOR THE UKRAINE IN 1996.

Input			Output			Estimated
Product	Reported	Estimated	Product	Reported	Estimated	I-O coef.
Industrial roundwood						
	10^3m^3			10^3m^3		m^3m^{-3}
	N/A	5 047	Sawnwood	N/A	2 102	2.40
	N/A	55	Plywood	11	11	5.00
	N/A	564	Particleboard	240	240	2.35
	N/A	89	Fiberboard	35	35	2.53
				10^3t		m^3t^{-1}
	N/A	58	Mechanical wood pulp	18	18	3.20
	N/A	151	Chemical wood pulp	32	32	4.72
Total	5 963	5 963				
Mechanical wood pulp						
	10^3t					tt^{-1}
	N/A	4	Newsprint	15	15	0.29
	N/A	10	Printing & writing paper	30	30	0.34
	N/A	4	Other paper & paperboard	243	243	0.01
Total	18	18				
Chemical wood pulp						
	N/A	1	Newsprint			0.05
	N/A	2	Printing & writing paper			0.07
	N/A	72	Other paper & paperboard			0.30
Total	75	75				
Other fiber pulp						
	N/A	0	Newsprint			0.00
	N/A	0	Printing & writing paper			0.00
	N/A	0	Other paper & paperboard			0.00
Total	0	0				
Waste paper						
	N/A	11	Newsprint			0.76
	N/A	18	Printing & writing paper			0.60
	N/A	175	Other paper & paperboard			0.72
Total	227	204				
Total fiber						
	N/A	17	Newsprint			1.10
	N/A	30	Printing & writing paper			1.00
	N/A	250	Other paper & paperboard			1.03
Total	320	297				

Note: Numbers may not add up due to round-off errors.

TABLE 9. DIFFERENCE BETWEEN ESTIMATED AND REPORTED PRODUCTION.

			Region				
Product	Production		Africa	America	Asia & Oceania	Europe & Former USSR	World
Industrial roundwood							
	Reported	10^3m^3	35900	703029	246353	352217	1337498
	Estimated	10^3m^3	37817	703594	251850	359333	1362596
	Difference	%	5.3	0.1	6.3	2.0	1.9
Sawnwood							
	Reported	10^3m^3	8948	206847	105244	110145	431183
	Estimated	10^3m^3	10110	207891	105424	114159	437585
	Difference	%	13.0	0.5	0.2	3.6	1.5
Plywood							
	Reported	10^3m^3	425	21475	26310	4590	52800
	Estimated	10^3m^3	425	21475	26333	4599	52833
	Difference	%	0.0	0.0	0.1	0.1	0.1
Particleboard							
	Reported	10^3m^3	774	24824	9325	29462	64385
	Estimated	10^3m^3	774	24824	9326	29462	64386
	Difference	%	0.0	0.0	0.0	0.0	0.0
Fiberboard							
	Reported	10^3m^3	78	8784	5969	6703	21533
	Estimated	10^3m^3	78	8784	5977	6703	21542
	Difference	%	0.9	0.0	0.1	0.0	0.0
Mechanical wood pulp							
	Reported	10^3t	403	17137	3932	12519	33991
	Estimated	10^3t	524	17154	3885	16071	37635
	Difference	%	30.1	0.1	–1.2	28.4	10.7
Chemical wood pulp							
	Reported	10^3t	1362	71040	15914	24084	112400
	Estimated	10^3t	1448	71047	15746	24164	112405
	Difference	%	6.3	0.0	–1.1	0.3	0
Other fiber pulp							
	Reported	10^3t	199	959	14198	235	15591
	Estimated	10^3t	199	955	14193	235	15583
	Difference	%	0.0	–0.4	0.0	0.0	-0.1
Newsprint							
	Reported	10^3t	493	16249	7322	10670	34734
	Estimated	10^3t	556	16261	7554	10722	35093
	Difference	%	12.6	0.1	3.2	0.5	1.0
Printing & writing paper							
	Reported	10^3t	9204	30307	22785	28300	90596
	Estimated	10^3t	9672	30307	22786	28300	91066
	Difference	%	5.1	0.0	0.0	–0.4	0.5
Other paper & paperboard							
	Reported	10^3t	1687	66503	54714	41120	164024
	Estimated	10^3t	1687	66503	54714	41120	164024
	Difference	%	0.0	0.0	0.0	0.0	0.0
Waste paper							
	Reported	10^3t	946	37614	34898	32767	106224
	Estimated	10^3t	906	37860	36638	32453	107857
	Difference	%	–4.2	0.7	5.0	–1.0	1.5

SUMMARY AND DISCUSSION

The purpose of this study was to estimate wood and fiber utilization accounts for forest sector analysis and forecasting with multi-country models. The method uses the national data and prior knowledge of techniques of production, while recognizing that the data are subject to measurement error. For this purpose, the techniques of linear regression and goal programming were applied under four main assumptions:

a. people in richer countries consume systematically more wood products than people in countries with lower income,

b. export and import data are more reliable than domestic production data,

c. the data of expensive wood products are more accurate than the data of cheaper products, and

d. input-output coefficients are distributed symmetrically within bounds defined by prior information on technologies (expert knowledge).

The first step of the method consisted in estimating final product consumption for countries without data or with obvious errors. This estimation was based on regressions of per capita consumption on per capita GDP. Given the trade data, production was then estimated. This first estimate of production was then refined simultaneously with other data in the second step.

The second step produced wood and fiber utilization accounts for each country and the corresponding I-O coefficients, by goal programming. The system gave estimates of production near the reported data, and input-output coefficients near the prior estimates based on prior knowledge (e.g. experts' opinions).

For some countries, like the United States, the method made only slight adjustments to the data, and the input-output coefficients had values consistent with the efficient technology of this country. For other countries, the estimated data differed substantially from the reported. In some cases, like the Ukraine, the method gave estimates of production for sectors without any data, while yielding input-output coefficients consistent with relatively inefficient technologies, as expected. Missing data were common in countries of the former Soviet Union. This is to be expected, given the recent political turmoil of these countries, and the fact that they are just beginning to rebuild their statistical apparatus. The proposed method should be most useful in those conditions.

The results for each country depend critically on the range of the prior input-output coefficients that are used. Thus, in an ideal procedure, after a first set of estimates is obtained, the results should be examined carefully. Then, the prior bounds on the input-output coefficients could be altered if it is deemed that the differences between estimated and reported data are too large. Nevertheless, the results suggest that improvements in international forest product data are still necessary. In the case of mechanical pulp, for example, the reported data do not seem very convincing given the large discrepancies between estimated and reported world production.

There were also large discrepancies between reported and estimated data in many small low-income countries. For example, important basic data on production were missing in several African countries for some products. But, there were discrepancies in some large industrialized countries as well. The pulp data in particular seem to be inaccurate.

The method could be improved in several ways. In particular, the bounds on input-output parameters could be refined by using other information on forest industries besides expert opinion. Furthermore, although the trade data have been assumed to be error free in this exercise, this assumption could be lifted. The import and export data would then be treated like the production data, with the goal of obtaining estimated trade data close to, but not necessarily equal to, the reported data. The weighting system would correspondingly be expanded to reflect the relative importance given to production data, prior I-O coefficients, and trade data. The drawback, apart from the added complication, is that adding variables in the model increases the possibility of multiple solutions, all leading to the same value of the objective function. The choice of one solution rather than another is then arbitrary. The probability of multiple solutions decreases with the number of constraints. Thus, assuming that the trade data are exact reduces the possibility of multiple solutions, although it does not eliminate it. Changing the objective function, for example to reflect the entropy principle (Golan *et al.*, 1996), might ensure a unique solution, at the cost of solving some difficult non-linear problems. Other approaches can also be used to improve the trade data only (e.g. Kornai, 1987).

The estimation method presented here was developed mainly to improve the parameters in models such as the GFPM, to forecast production, trade, and prices, for many countries and products. The coherence and plausibility of the basic data and relations is essential to get useful forecasts. But, the method should also have value in basic statistical work, to check the accuracy of data on the international forest sector as they are being collected.

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