Forestry An International Journal of Forest Research

Institute of Chartered Foresters

Forestry 2018; **91**, 541–551, doi:10.1093/forestry/cpy025
Advance Access publication 17 August 2018

On the accuracy of international forest product statistics

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Received 1 June 2018

To judge the accuracy of international forest product statistics, we checked the consistency of the reported consumption of wood and fiber with the production of wood products. Using goal programming, we estimated for 180 countries the consumption of industrial roundwood and of paper-making fibers nearest to the reported consumption, given the reported production of sawnwood, wood-based panels, pulp and paper and paperboard, and prior estimates of the input–output coefficients. The results suggested that for the 3-year average 2013–2015, industrial roundwood consumption was under-reported in 57 countries by a total amount of 368 million m^3 and over reported in 44 countries by a total of 16 million m^3. The largest under-reporting was for China for which the reported consumption of industrial roundwood was 237 million m^3, or 57 per cent less than the estimated. The largest over reporting was for India, by 11 million m^3, or 24 per cent. For paper-making fibers, reported consumption was less than the estimated in 62 countries for a total of 11.3 million t, and it was more than the estimated in 61 countries, for a total of 3.2 million t. The largest under-reported amount was for India: 2.6 million t, or 20 per cent of the estimated, a difference that was entirely attributed to the under-reporting of recovered paper consumption. The largest over reported consumption of paper-making fibers was for Spain, nearly 1 million t, or 24 per cent, attributed to over reporting of recovered paper consumption. The main source of the discrepancies was in the production statistics rather than trade. Only in some instances was the presumption of illegal logging consistent with the discrepancy, or lack thereof, between reported and estimated consumption of industrial roundwood.

Introduction

Statistics on forest product industries are constantly being quoted and analyzed. They are the essential pillar of forest sector models such as the Global Forest Products Model (GFPM; Buongiorno *et al.*, 2003), the European Forest Institute Global Trade Model (EFI-GTM; Kallio *et al.*, 2004) and the Global Biosphere Management Model (GLOBIOM; Lauri *et al.*, 2013). The reliability of the analyses and projections obtained with these models depends in part on the soundness of the theoretical structure, and also on the accuracy of the parameters and initial conditions (Kallio, 2010; Buongiorno and Johnston, 2018), which in turn depend on the accuracy of published statistics.

For international forest sector studies a unique and essential database is the Forest Products Yearbook of the Food and Agriculture Organization of the United Nations (FAO, 2017a), which is also available in electronic form as the FAOSTAT database (FAO, 2017b). The FAOSTAT has annual time series starting in 1960 on the production, imports and exports (in value and quantity), and direction of trade, for all countries and major products ranging from fuelwood to paper and paperboard.

It is known that international data of all kinds have substantial errors (Morgenstern, 1963; Boumans, 2012; Jerven, 2014), but few have examined specifically forest product statistics. Michie and Wardle (1998) deal indirectly with this issue by proposing ways to estimate bilateral trade flows of coniferous sawnwood where data are missing, and Buongiorno and Zhu (2015) estimate input–output coefficients and manufacturing costs for the GFPM model with a method that takes into account potential errors in all production statistics, but with several assumptions, such as the relative weight of errors in different product categories. Independently of the present study, Kallio and Solberg (2018) have also documented inconsistencies in the FAOSTAT statistics.

The objective of the present study was to reveal directly and with a minimum of assumptions potential discrepancies in the FAOSTAT database. The remainder of the paper is organized as follows: the next section presents the methods, in which the guiding idea was to check the consistency of input statistics, such as the apparent consumption of industrial roundwood, with the production of products such as sawnwood, panels and wood pulp. This is followed by the results which showed large differences in several countries between reported and expected consumption of industrial roundwood and of paper-making fibers. Part of the last section discusses some of the reasons for the observed discrepancies, not all of which could be attributed to illegal logging or unreported trade.

Methods and data

The objective was to estimate by country the consumption of wood and fiber inputs consistent with the reported production of various outputs and prior estimates of input–output coefficients.

The specific inputs considered were:

- industrial roundwood
- paper-making fibers

Paper-making fibers were further disaggregated in:

- Mechanical pulp
- Chemical pulp (including semi-chemical)
- Recovered paper
- Other paper-making fibers

The outputs made from industrial roundwood were:

- Sawnwood
- Veneer and plywood
- Particleboard
- Fiberboard
- Mechanical pulp
- Chemical pulp (including semi-chemical)

The outputs made from paper-making fibers were:

- Newsprint
- Printing and writing paper (except newsprint)
- Other paper and paperboard

The data were the statistics reported in the FAOSTAT database (FAO, 2017b), for the 180 countries listed in Appendix A. The consumption of each input was defined as production plus imports minus exports. To minimize the effect of changes in stocks the consumption and production data were averaged over three years: 2013, 2014, 2015.

The method used goal programming. The objective was to estimate consumption data for industrial roundwood and paper-making fibers as near as possible to the reported statistics, while respecting prior limits on the amount of input needed per unit of output. An example with statistics for India is given in Appendix B.

The variables and parameters used in the model were:

C_{im}: estimated amount of input m consumed in country i,

C^0_{im}: reported amount of input m consumed in country i,

C^-_{im}: amount by which the estimated input m fell short of the reported,

C^+_{im}: amount by which the estimated input m exceeded the reported,

C_{imp}: estimated amount of input m consumed in making product p in country i,

r^L_{imp}: lower bound on amount of a single input m per unit of output p in country i,

r^U_{imp}: upper bound on amount of a single input m per unit of output p in country i,

r_{imp}: estimated amount of a single input m per unit of output p in country i,

r^L_{itp}: lower bound on total amount of multiple inputs per unit of output p in country i,

r^U_{itp}: upper bound on total amount of multiple inputs per unit of output p in country i,

r_{itp}: estimated total amount of multiple inputs per unit of output p in country i,

Q^0_{ip}: reported amount of output p produced in country i,

D_{im}: difference between reported and estimated amount of input m in country i,

R_{im}: per cent difference between reported and estimated amount of input m in country i,

The objective of the problem was to find the variables C_{imp}, $C^-_{imp}C^+_{imp}$, all non-negative, that minimized the sum of the deviations between estimated and reported consumption of industrial roundwood and paper-making fibers:

$$min \sum_{i,m} (C^-_{im} + C^+_{im}) \tag{1}$$

Subject to:

Single input consumed in multiple outputs:

$$C_{im} = \sum_{p} C_{imp} \quad \forall\, i, m \tag{2}$$

Deviation of estimated from reported consumption of input:

$$C_{im} + C^-_{im} - C^+_{im} = C^0_{im} \quad \forall\, i, m \tag{3}$$

Prior lower and upper bound on single input in each output:

$$r^L_{imp} Q^0_{ip} \le C_{imp} \le r^U_{imp} Q^0_{ip} \quad \forall\, i, m, p \tag{4}$$

Total of multiple inputs consumed in each output:

$$C_{itp} = \sum_{m} C_{imp} \;\; \forall\, i, t, p \tag{5}$$

Prior lower and upper bound on total of multiple inputs in each output:

$$r^L_{itp} Q^0_{ip} \le C_{itp} \le r^U_{itp} Q^0_{ip} \quad \forall\, i, t, p \tag{6}$$

Equations (1–4) sufficed to estimate the national consumptions of industrial roundwood, or of total paper-making fibers, that best approached the reported statistics while satisfying the prior limits on the amounts of industrial roundwood, or total paper-making fibers needed per unit of output.

The additional constraints (5) and (6) were used in estimating the more detailed paper-making fiber consumption (mechanical pulp, chemical pulp, recovered paper and other fibers), recognizing that in making a particular paper grade, say newsprint, various fiber types could be combined, for example, mechanical pulp with chemical pulp, or recovered paper, or other paper-making pulp.

A property of goal programming is that in the optimum solution, either C^-_{im} is positive and C^+_{im} is zero (Hillier and Lieberman, 1990, p. 268), in which case the estimated consumption of the input m in country i falls short of the reported, or C^+_{im} is positive and C^-_{im} is zero, indicating that estimated consumption exceeds the reported. The difference between reported and estimated consumption was then, from constraint (3):

$$D_{im} = C^-_{im} - C^+_{im} = C^0_{im} - C_{im} \quad \forall\, i, m \tag{7}$$

And the per cent relative difference was:

$$R_{im} = \frac{C^0_{im} - C_{im}}{C_{im}} * 100 \quad \forall\, i, m \tag{8}$$

The input–output coefficients implied by the solution where then, for a single input per unit of output:

$$r_{imp} = \frac{C_{imp}}{Q^0_{ip}} \quad \forall\, i, m, p \tag{9}$$

And for the cumulative multiple inputs per unit of output:

$$r_{itp} = \frac{C_{itp}}{Q^0_{ip}} \quad \forall\, i, m, p \tag{10}$$

The prior data on the lowest and highest amount of industrial roundwood r^L_{imp} and r^U_{imp} used per unit of products are in Table 1. They were the lowest and highest amounts reported by 38 countries of the United Nations Economic Commission for Europe (UNECE, 2010). In the making of paper and paperboard, it was assumed that at least $r^L_{imp} = 0.95$ t of fiber per ton of paper and paperboard was needed, somewhat less than 1t to account for various fillers used in paper-making. And, the maximum amount of fiber used was set at $r^U_{imp} = 1.10$ t/t to allow for waste. In estimating the amount of each type of pulp being consumed it was further assumed that the total amount of different fiber types combined in making paper or paperboard was also between $r^L_{itp} = 0.95$ and $r^U_{itp} = 1.10$ t/t in equation (6).

Results

The results in Tables 2–7 show, for each input type from industrial roundwood to recovered paper, the absolute and per cent differences between reported and estimated input, obtained with equations (7) and (8) above and for the 180 countries in Appendix A. For each input type, only differences of at least 1 000 m^3 or 1 000 t were tabulated, in accord with the precision of published FAO statistics (FAO, 2017a).

Reported vs estimated industrial roundwood consumption

Table 2 shows that for 17 of the 180 countries in Appendix A, the reported consumption was at least 1 million m^3 less than the estimated. For two countries reported consumption exceeded the estimated by more than 1 million m^3. For the world total, the under-reporting was much larger than the over reporting: approximately 368 million m^3 versus 16 million m^3. The largest national undereporting was for China for which the reported consumption of industrial roundwood was 237 million m^3, or 57 per cent less than the estimated. This inferred under-reported consumption for China was larger than the reported total production of Latin America in 2015 (FAO, 2017a, p. 22). The second largest under-reporting was for the USA where reported consumption was 10 per cent less than estimated. Vietnam, Japan and Thailand came next in absolute differences, with reported consumption 147 per cent, 23 per cent and 68 per cent less than estimated, respectively.

For all the countries inferred to be under-reporting industrial roundwood consumption (negative differences in Table 2), the computed input–output coefficients obtained with equation (9) were all at their lower bounds shown in Table 1. Thus, the negative differences in Table 2 assumed the most efficient technologies (in terms of raw material usage) reported in the 38 UNECE countries, for all countries in Appendix A and for all industries: sawmills, wood-based panels manufactures and pulp mills. Consequently, the negative differences were likely to be conservative in the sense of underestimating the under-reporting of industrial roundwood consumption rather than overestimating it.

Among the countries where reported consumption of industrial roundwood exceeded the estimated, the extreme case was India which, according to the results in Table 2 reported about 11 million m^3 (24 per cent) more of industrial roundwood consumption than expected from the production of sawnwood, wood panels and wood pulp in India. Far behind was Paraguay where the reported consumption exceeded the estimated by about 1 million m^3, or 45 per cent. For all the countries that reported more industrial roundwood consumption than estimated, the input–output coefficients were at their upper bounds shown in Table 1, implying the most inefficient transformations of roundwood into products observed within UNECE countries. The actual inefficiency in other countries might be worse, in which case the positive data in Table 2 might overestimate the difference between reported and actual consumption.

Reported vs. estimated consumption of total paper-making fiber

The national differences between the reported and estimated consumption of total paper-making fiber (mechanical and chemical wood pulp, recovered paper and other paper-making fiber) conditional on the production of paper and paperboard (newsprint, printing and writing paper, other paper and paperboard) and conditional on the bounds on conversion factors, are in Table 3. In 21 of the 180 countries considered, the reported annual consumption fell short of the estimated consumption by at least 100,000 t. In 6 countries, the reported consumption exceeded the estimated by 100 000 t. For the whole world, the under-reported production of total paper-making fiber amounted to 11.3 million t, while the over reported was 3.2 million t. In India, the reported production fell short of the estimated by 2.6 million t, or 20 per cent, an amount nearly equal to all the total paper-making fiber reported production for Austria. The other two largest inferred under-reporting countries were Finland by 1.6 million t, or 17 per cent, and Canada by 1.1 million t, or 11 per cent.

Reported vs. estimated mechanical pulp consumption

Table 4 shows that in 16 countries the reported consumption of mechanical pulp was less than the estimated consumption. For the whole world, the total inferred under-reporting of consumption amounted to 881 000 t and the total over reporting to 332 000 t. The largest inferred under-reporting of consumption was for Austria for which reported consumption fell short of the estimated by 373 000 t, or 49 per cent. For Austria, the inferred under-reporting of mechanical pulp accounted in full for the

Table 1 Lowest and highest amount of industrial roundwood used per unit of output. Source: UNECE, 2010, Annex Table 3

	Sawnwood m^3/m^3	Veneer and Plywood m^3/m^3	Particleboard m^3/m^3	Fiberboard m^3/m^3	Mechanical pulp m^3/t	Chemical pulp m^3/t
Low	1.4	1.5	1.2	1.5	1.2	4.5
High	3.5	3.1	1.8	3.3	2.9	6.4

Table 2 Difference of more than 1000 m^3 between reported and estimated consumption of industrial roundwood

Country	1000 m^3	%	Country	1000 m^3	%	Country	1000 m^3	%
China	−237 452	−57	Greece	−171	−29	Barbados	8	–
United States	−35 213	−10	Israel	−156	−84	Kuwait	8	–
Vietnam	−17 608	−145	Kyrgyzstan	−153	−96	Botswana	9	–
Japan	−13 587	−23	Montenegro	−145	−59	Turkmenistan	13	–
Thailand	−10 651	−68	Ethiopia	−134	−77	Mauritius	13	376
Germany	−8380	−15	Luxembourg	−96	−14	Tajikistan	16	–
Malaysia	−4949	−28	Togo	−93	−98	Qatar	20	–
Romania	−4762	−32	Egypt	−75	−26	Samoa	24	690
Australia	−4266	−30	Jamaica	−72	−78	Oman	37	–
Spain	−3932	−25	Guinea-Bissau	−72	−322	Bahamas	38	1081
France	−2880	−12	Albania	−37	−149	Central Afr. Rep.	45	37
Iran	−2614	−84	Bhutan	−33	−48	Burkina Faso	56	319
Ukraine	−2257	−38	Syria	−33	−65	Gambia	65	1852
Portugal	−2141	−15	Sierra Leone	−30	−424	Guyana	67	22
Korea, Rep.	−1828	−18	Congo, DR	−28	−13	Macedonia	102	624
Italy	−1722	−23	Lebanon	−15	−20	Saudi Arabia	113	–
Venezuela	−1262	−67	Angola	−6	−7	Burundi	179	142
United Kingdom	−931	−10	Niger	−4	−64	U. Arab Emirates	187	–
Ecuador	−911	−39	Equat. Guinea	−3	−12	Haiti	189	386
Pakistan	−903	−30	Belize	−3	−5	Swaziland	348	69
Uruguay	−845	−9	Jordan	1	–	Rwanda	489	103
Mexico	−739	−13	Saint Lucia	1	–	Sudan	534	916
Austria	−716	−3	Timor-Leste	1	–	Tanzania	574	115
Singapore	−664	−118	Djibouti	1	–	Uganda	607	38
Myanmar	−627	−24	St Vincent/Grenadines	1	–	El Salvador	611	1091
Slovakia	−552	−9	Yemen	1	–	Paraguay	1079	45
Kazakhstan	−507	−79	Tonga	1	19	India	10 770	24
Bulgaria	−498	−17	Martinique	2	43			
Mozambique	−447	−129	Moldova	3	5			
Bangladesh	−437	−67	Fiji Islands	4	1			
Benin	−324	−157	Bahrain	4	–			
Estonia	−313	−8	New Caledonia	4	37			
Sri Lanka	−306	−90	Lesotho	4	–			
Colombia	−274	−13	Dominica	4	–			
Philippines	−235	−17	Cook Islands	4	–			
Slovenia	−234	−16	Azerbaijan	5	–			
Cuba	−177	−46	Chad	7	95			

Negative numbers indicate that reported consumption was less than estimated.
% was relative to estimated consumption, '–' indicates that estimated consumption was zero.
Data were three year averages for 2013, 2014 and 2015.

inferred under-reporting of total paper-making fiber (Table 3). This was also true for Croatia and Egypt.

At the other extreme, the largest inferred over reporting of mechanical pulp consumption was for the UK: 224 000 t instead the estimated zero consumption, followed by Switzerland (52 000 t or 72 per cent more than estimated) and Bangladesh (Table 4).

Reported vs. estimated chemical pulp consumption

According to the results in Table 5, in 22 of the 180 countries considered, the difference between reported and inferred consumption of chemical pulp exceeded 1 000t in 2014. For the world, the total inferred under-reported consumption amounted to 3.8 million t, while the total over reporting was 0.8 million t. The largest national under-reporting was for Canada: 1.15 million t or 64 per cent of the expected consumption, followed by Finland (nearly 1 million t or 17 per cent), and Hungary (325 000 t, or 75 per cent). For Canada and Hungary, the inferred under-reporting of chemical pulp accounted fully for that of total paper-making fiber (Table 3). Among countries where the reported consumption exceeded the estimated, Bangladesh and Singapore had the largest differences (279 000 t and 123 00 t reported consumption, respectively, instead of the zero estimated consumption). For these two countries, the discrepancy

Table 3 Differences of more than 1000 t between reported and estimated consumption of total paper-making fiber

Country	1000 t	%	Country	1000 t	%	Country	1000 t	%
India	−2610	−20	Bhutan	−11	−111	Ghana	2	–
Finland	−1638	−17	Iraq	−9	−76	Guyana	2	–
Canada	−1145	−11	Azerbaijan	−8	−86	Fiji Islands	2	–
Belgium	−728	−38	Tunisia	−8	−5	Costa Rica	2	1
Ukraine	−490	−48	Armenia	−8	−96	Uganda	2	–
Austria	−373	−8	Luxembourg	−7	−33	Senegal	3	–
Hungary	−325	−46	Barbados	−5	−275	Montenegro	3	–
Denmark	−310	−68	French Polynesia	−5	–	Panama	3	–
Peru	−308	−60	Georgia	−5	−39	Albania	3	–
Vietnam	−308	−19	Uzbekistan	−4	−17	Jamaica	4	–
Bulgaria	−271	−83	U. Arab Emirates	−3	−1	Laos	4	–
Croatia	−263	−98	Zambia	−3	−82	Mozambique	4	203
Serbia	−258	−56	Libya	−3	−53	Cuba	5	18
Greece	−246	−63	Moldova	−3	−39	Côte d'Ivoire	5	–
Iran	−244	−34	Turkey	−3	0	Cambodia	6	–
Belarus	−233	−79	Congo, Rep.	−3	−88	Algeria	7	13
Kazakhstan	−165	−79	Bahamas	−2	–	Ecuador	7	3
The Netherlands	−147	−6	Congo, DR	−2	−77	Djibouti	9	–
Malaysia	−131	−7	Qatar	−2	−77	Kuwait	11	28
Saudi Arabia	−128	−11	Bosnia Herzegovina	−2	−1	Sudan	12	318
Dominican Rep.	−100	−81	Lesotho	−1	–	Tanzania	13	30
Uruguay	−82	−68	Burkina Faso	−1	−100	Trinidad Tobago	14	105
Madagascar	−77	−98	Mauritania	−1	−100	Bolivia	16	–
Honduras	−73	−102	Togo	−1	–	Paraguay	17	121
Slovakia	−59	−8	Haiti	−1	–	Nigeria	18	88
Slovenia	−57	−8	Lithuania	1	0	Angola	20	–
Syria	−55	−78	Chad	1	–	Korea, DPR	24	28
Egypt	−50	−8	Mauritius	1	–	Myanmar	26	52
Norway	−46	−5	Brunei	1	–	Kenya	30	–
Lebanon	−46	−47	Nepal	1	5	Bahrain	30	226
Ethiopia	−45	−61	Cameroon	1	–	Morocco	39	23
Ireland	−45	−79	Sierra Leone	1	–	Switzerland	44	3
Swaziland	−38	−81	Martinique	1	–	Estonia	47	60
Macedonia	−25	−100	Vanuatu	1	–	Romania	52	12
Guatemala	−23	−80	Tajikistan	1	–	Philippines	52	6
Sweden	−20	0	Mongolia	1	–	Oman	53	1203
Pakistan	−13	−1	Niger	1	–	New Zealand	53	7

Negative numbers indicate that reported consumption was less than estimated.
% was relative to estimated consumption, '–' indicates that estimated consumption was zero.
Data were 3-year averages for 2013, 2014 and 2015.

Country	1000 t	%
Venezuela	58	16
Mali	61	–
Zimbabwe	61	–
Jordan	84	141
Czech Rep.	93	13
South Africa	99	4
Singapore	140	147
Colombia	149	11
Argentina	211	16
United Kingdom	249	5
Bangladesh	339	531
Spain	988	14

Negative numbers indicate that reported consumption falls short of estimated.
'–' indicates that % difference is undefined because estimated consumption is zero.
Data are for 3-year averages 2013, 2014 and 2015.

Table 4 Differences of more than 1000 t between reported and estimated mechanical pulp consumption.

Country	1000 t	%
Austria	−373	−49
Croatia	−263	−100
Peru	−63	−100
Slovenia	−54	−43
Egypt	−50	−87
Ukraine	−43	−100
Sweden	−20	−1
Ethiopia	−12	−100
Morocco	−3	–
Slovakia	−1	–
Côte d'Ivoire	2	–
Nigeria	6	–
Tanzania	12	–
Bangladesh	36	–
Switzerland	52	72
UK	224	–

Negative numbers indicate that reported consumption was less than estimated.
% was relative to estimated consumption, '–' indicates that estimated consumption was zero.
Data were 3-year averages for 2013, 2014 and 2015.

between reported and estimated chemical pulp consumption covered only a part of the discrepancy for total paper-making fiber (Table 3).

Reported vs. estimated recovered paper consumption

For 37 countries, the reported consumption of recovered paper was 1000 t less than the estimated amount (Table 6), and the total under-reporting at world level amounted to 5.1 million t. Reported consumption exceeded the estimated in 42 countries, with a world total of 1.8 million t. The largest difference between reported and estimated consumption was for India: 2.6 million t, or 32 per cent. This inferred under-reporting of recovered paper matched the under-reporting of total paper-making fiber in India (Table 3). Finland and Ukraine were the other two countries with the largest inferred under-reporting of recovered paper consumption, respectively, at 667 000 t (54 per cent) and 447 000 t (49 per cent), but in these two countries this was only a part of the under-reporting of total paper-making fiber (Table 2). Among the countries where the reported consumption exceeded the estimated, the largest differences were for Spain (nearly 1 million t, or 24 per cent) and Argentina (211 000 t or 45 per cent). For these two countries, the inferred over reporting of recovered paper accounted for the over reporting of the total paper-making fiber shown in Table 2.

Reported vs. estimated consumption of other paper-making fiber

As shown in Table 7, the reported consumption of paper-making fiber other than wood pulp or recovered paper was less than the

Table 5 Difference of more than 1000 t between reported and estimated consumption of chemical pulp.

Country	1000 t	%	Country	1000 t	%
Canada	−1145	−64	Cuba	3	–
Finland	−971	−17	Algeria	4	8
Hungary	−325	−75	Laos	4	–
Serbia	−258	−87	Albania	4	–
Greece	−246	−65	Bolivia	6	–
Belarus	−205	−80	Djibouti	9	–
Denmark	−172	−81	Trinidad Tobago	10	74
Malaysia	−131	−32	Kuwait	11	161
Dominican Rep.	−100	−88	Nigeria	16	77
Syria	−55	−78	Angola	20	–
Ireland	−45	−90	Estonia	21	26
Uruguay	−29	−52	Korea, DPR	24	103
Guatemala	−23	−80	Bahrain	28	–
Ethiopia	−17	−65	New Zealand	39	24
Pakistan	−13	−7	Venezuela	58	54
Bhutan	−9	−89	Jordan	59	99
Armenia	−8	−96	Czech Republic	94	22
Uzbekistan	−4	−35	Singapore	123	–
U. Arab Emirates	−3	−2	Bangladesh	279	–
Libya	−3	−53			
Turkey	−3	0			
Congo, DR	−2	−77			
Mauritius	1	–			
Senegal	1	–			
Zimbabwe	1	–			
Belize	1	–			
Lithuania	1	10			
Cameroon	1	–			
Sierra Leone	1	–			
Vanuatu	1	–			
Mongolia	1	–			
Oman	1	–			
Panama	2	–			
Kenya	2	–			
Niger	2	–			
New Caledonia	2	–			
Mozambique	3	–			

Negative numbers indicate that reported consumption was less than estimated.
% was relative to estimated consumption, '–' indicates that estimated consumption was zero.
Data were 3-year averages for 2013, 2014 and 2015.

estimated amount by at least 1000 m^3 in 16 countries, for a total world under-reporting of 1.5 million t. In 7 countries the reported consumption exceeded the estimated by a total of 212 000 t. The largest inferred under-reporting was for Belgium: 375 000 t, or 99 per cent less than the estimated consumption based on the production of newsprint, printing and writing paper, and other paper and paperboard in Belgium. This discrepancy covered only part of the under-reporting of total paper-making fiber (728 000 t, see Table 3),

Table 6 Difference of more than 1000 t between reported and estimated consumption of recovered paper

Country	1000 t	%	Country	1000 t	%	Country	1000 t	%
India	−2610	−32	Chad	1	–	Mali	61	–
Finland	−667	−54	Brunei	1	–	Zimbabwe	61	–
Ukraine	−447	−49	Algeria	1	–	South Africa	99	10
Belgium	−353	−37	Martinique	1	–	Argentina	211	45
Vietnam	−308	−31	Panama	1	–	Spain	988	24
Peru	−246	−71	Tajikistan	1	–			
The Netherlands	−147	−7	Tanzania	1	–			
Honduras	−73	−102	Ghana	2	–			
Norway	−46	−21	Bahrain	2	14			
Lebanon	−46	−66	Mozambique	2	82			
Swaziland	−38	−81	Senegal	2	–			
Belarus	−28	−68	Guyana	2	–			
Macedonia	−25	−100	Fiji Islands	2	–			
Iraq	−9	−100	Costa Rica	2	4			
Azerbaijan	−8	−89	Cuba	3	9			
Tunisia	−8	−13	Montenegro	3	–			
Luxembourg	−7	−33	Côte d'Ivoire	3	–			
Barbados	−5	−275	Sudan	3	–			
French Polynesia	−5	–	Uganda	3	–			
Georgia	−5	−39	Jamaica	4	–			
Nigeria	−4	–	Trinidad Tobago	4	–			
Bulgaria	−4	–	Myanmar	4	13			
Moldova	−3	−39	Bangladesh	6	9			
Congo, Rep.	−3	−88	Cambodia	6	–			
Slovenia	−2	−1	Ecuador	7	3			
Bahamas	−2	–	Bolivia	10	–			
Qatar	−2	−77	New Zealand	15	7			
Bhutan	−2	–	Jordan	17	–			
New Caledonia	−2	–	Paraguay	17	119			
Zambia	−1	−65	Singapore	18	19			
Lesotho	−1	–	UK	25	1			
Albania	−1	–	Estonia	27	–			
Burkina Faso	−1	−100	Kenya	28	–			
Mauritania	−1	−100	Morocco	37	47			
Niger	−1	–	Romania	51	16			
Togo	−1	–	Oman	52	1173			
Haiti	−1	–	Philippines	52	6			

Negative numbers indicate that reported consumption was less than estimated.
% was relative to estimated consumption, '–' indicates that estimated consumption was zero.
Data were 3-year averages for 2013, 2014 and 2015.

Summary and discussion

The objective of this study was to investigate the accuracy of international forest product statistics available in the FAOSTAT database. The database is unique for its coverage of all countries, over a time period ranging from 1960 to recent years, and with products detail covering raw wood, manufactured solid wood products (sawnwood and panels), paper-making fibers (wood pulp, recovered paper, other fibers), and paper and paperboard.

The approach consisted in checking the consistency of raw materials consumption statistics with those of products production. This was done with a goal programming model. The model estimated the national consumption of industrial roundwood and paper-making fibers based on the reported production of sawnwood, panels and paper and paperboard. The estimated consumption was as near as possible to the reported consumption statistics in the FAOSTAT, while keeping input–output coefficients within plausible ranges.

The method was applied to 180 countries with data averaged for the years 2013, 2014, and 2015. The results revealed large discrepancies in several countries between reported and estimated consumption of industrial roundwood an paper-making fibers. The general tendency was for reported consumption to be less than the estimated. For industrial roundwood the

Table 7 Difference of more than 1000 t between reported and estimated consumption of paper-making fiber other than wood pulp and recovered paper

Country	1000 t	%
Belgium	−375	−99
Bulgaria	−267	−100
Iran	−244	−83
Kazakhstan	−165	−101
Denmark	−138	−94
Saudi Arabia	−128	−64
Madagascar	−76	−97
Slovakia	−58	−100
Uruguay	−53	−100
Ethiopia	−16	−64
Switzerland	−8	–
Zambia	−2	−100
Bosnia Herzegovina	−2	−100
Uganda	−1	–
Zimbabwe	−1	–
Czech Rep.	−1	–
Algeria	2	–
Morocco	5	–
Jordan	8	–
Sudan	8	227
Bangladesh	18	–
Myanmar	21	138
Colombia	149	366

Negative numbers indicate that reported consumption was less than estimated.
% was relative to estimated consumption, '–' indicates that estimated consumption was zero.
Data were 3-year averages for 2013, 2014 and 2015.

largest difference was for China where reported consumption fell short of the estimated by 237 million m^3, or 57 per cent. For paper-making fibers, the largest discrepancy was for India where reported consumption was 2.6 million t, or 20 per cent less than estimated consumption.

For paper-making fibers, the method gave further detail by fiber type (mechanical pulp, chemical pulp, recovered paper, or other fiber). For example, it suggested that for India, the 2.6 million t of under-reported paper-making fiber consumption consisted entirely of mechanical pulp. However, the method assumed that fiber types could be substituted freely as long as the total amount of required fiber was satisfied (although it did keep the estimated consumption of each fiber type as close as possible to the observed). Thus, the discrepancies by fiber type were not as dependable as the discrepancies for total paper-making fibers.

In view of the magnitude of the discrepancies between reported and estimated consumption of industrial roundwood and paper-making fiber, one may wonder about their reason. Apparent consumption is defined as production plus imports minus exports. Thus, under-reported consumption may stem from under-reported production or imports, or from over reported exports. It is known that all trade statistics are subject to errors, and this is also true for forest products trade (Michie and Wardle, 1998), however, because of customs duties and regulations, they are likely to be more accurate than production statistics. For example, China's imports of industrial roundwood from all countries add up to only 8.5 million m^3 less than the exports to China reported by other countries (derived from FAO, 2017b), which is much less than the under-reported consumption of 237 million m^3 inferred above.

If one ignored the errors on import and export statistics, the discrepancies in consumption would be totally due to discrepancies in production. Then, some of the underestimation of industrial roundwood production could be attributed to illegal logging. This could explain the large under-reported consumption in China, where illegal logging may reach 50 per cent of the reported harvest (Miller *et al.*, 2006). Vietnam and Thailand are other countries where presumed extensive illegal logging (Seneca Creek Associates, 2004) could explain under-reported production and thus part of the under-reported industrial roundwood consumption in Table 2. However, in the USA, Japan and Germany, where illegal logging seems to be negligible according to the same authors, it cannot explain the under-reported consumption found in the present study.

Furthermore, while illegal logging has been suggested to take place in Russia, amounting to as much as 30 per cent of the wood harvest (Contreras-Hermosilla *et al.*, 2007), the present study found that Russia's reported consumption of industrial roundwood was plausible given its reported production of sawnwood, panels and wood pulp. And this did not appear to be due to a large under-reporting of industrial roundwood exports by Russia, as Russian exports to the world exceeded the imports by the world from Russia by only 728 thousand m^3 (derived from FAO, 2017b).

In sum, plain errors seem to be the most plausible explanation for the discrepancies between reported and estimated consumption of industrial roundwood and paper-making fibers. The discrepancies were quantified here by holding the production statistics of the derived products (sawnwood, panels, pulp, paper), at their reported level and estimating consistent consumption of industrial roundwood and paper-making fibers. However, part or all of the errors may lie in the statistics for the output products as well as in the inputs. Buongiorno and Zhu (2015) suggest an extension of the method used here to harmonize all production statistics, still conditional on trade statistics and prior input–output coefficients, but with more assumptions, in the form of weights implying more reliable data for the higher valued products. While this method is useful for model building and calibration, it does not solve the fundamental problem of the inaccuracy of the observations. There seems to be no substitute but to improve the data collection procedures. In this process, checking data consistency in a manner analog to the one adopted in this study should be helpful in detecting large errors and guiding the statistical work to correct them.

Conflict of interest statement

None declared.

Funding

The research leading to this paper was supported in part by the USDA Forest Service grant/agreement 17-JV-11330143-087, under the leadership of Dr Jeff Prestemon.

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Appendix A Countries used in the study

Afghanistan	Croatia	Japan	Norway	Timor-Leste
Albania	Cuba	Jordan	Oman	Togo
Algeria	Cyprus	Kazakhstan	Pakistan	Tonga
Angola	Czech Rep.	Kenya	Panama	Trinidad Tobago
Argentina	Denmark	Korea, DPR	Papua New Guinea	Tunisia
Armenia	Djibouti	Korea, Rep.	Paraguay	Turkey
Australia	Dominica	Kuwait	Peru	Turkmenistan
Austria	Dominican Rep.	Kyrgyzstan	Philippines	Uganda
Azerbaijan	Ecuador	Laos	Poland	Ukraine
Bahamas	Egypt	Latvia	Portugal	U. Arab Emirates
Bahrain	El Salvador	Lebanon	Qatar	UK
Bangladesh	Equat. Guinea	Lesotho	Réunion	USA
Barbados	Estonia	Liberia	Romania	Uruguay
Belarus	Ethiopia	Libya	Russia	Uzbekistan
Belgium	Fiji Islands	Lithuania	Rwanda	Vanuatu
Belize	Finland	Luxembourg	Saint Lucia	Venezuela
Benin	France	Macedonia	St Vincent/ Grenadines	Vietnam
Bhutan	Fr. Guiana	Madagascar	Samoa	Yemen
Bolivia	Fr. Polynesia	Malawi	Sao Tome Principe	Zambia
Bosnia Herzegovina	Gabon	Malaysia	Saudi Arabia	Zimbabwe
Botswana	Gambia	Maldives	Senegal	
Brazil	Georgia	Mali	Serbia	
Brunei	Germany	Martinique	Sierra Leone	
Bulgaria	Ghana	Mauritania	Singapore	
Burkina Faso	Greece	Mauritius	Slovakia	
Burundi	Guatemala	Mexico	Slovenia	
Cambodia	Guinea	Moldova	Solomon Islands	
Cameroon	Guinea-Bissau	Mongolia	Somalia	
Canada	Guyana	Montenegro	South Africa	
Cape Verde	Haiti	Morocco	Spain	
Central Afr. Rep.	Honduras	Mozambique	Sri Lanka	
Chad	Hungary	Myanmar	Sudan	
Chile	India	Nepal	Suriname	
China	Indonesia	The Netherlands	Swaziland	
Colombia	Iran	Neth. Antilles	Sweden	
Congo, Dem. Rep.	Iraq	New Caledonia	Switzerland	
Congo, Rep.	Ireland	New Zealand	Syria	
Cook Islands	Israel	Nicaragua	Tajikistan	
Costa Rica	Italy	Niger	Tanzania	
Côte d'Ivoire	Jamaica	Nigeria	Thailand	

Appendix B

This example deals with the estimation of industrial roundwood and paper-making fiber consumption for India. In actual implementation, the model was set up for all countries simultaneously.

Data

Table B1 shows the consumption and production data for India, averaged over the 3 years 2012, 2014 and 2015. Table B2 shows the prior bounds on the input–output coefficients.

Goal programming formulation

$$\min(C_{81}^{-} + C_{81}^{+} + C_{87}^{-} + C_{87}^{+} + \ldots + C_{90}^{-} + C_{90}^{+})$$

Subject to:

Single input consumed in multiple outputs:

$$C_{81} = C_{81,83} + C_{81,84} + \ldots + C_{81,88}$$
$$C_{87} = C_{87,91} + C_{87,92} + C_{87,93}$$
$$\ldots$$
$$C_{90} = C_{90,91} + C_{90,92} + C_{90,93}$$

Deviation of estimated from reported consumption:

$$C_{81} + C_{81}^{-} - C_{81}^{+} = 56054\ (1000\ \mathrm{m}^3)$$
$$C_{87} + C_{87}^{-} - C_{87}^{+} = 488\ (1000\ \mathrm{t})$$
$$\ldots$$
$$C_{90} + C_{90}^{-} - C_{90}^{+} = 5534\ (1000\ \mathrm{t})$$

Prior lower and upper bound on single input in each output:

$$1.4 \times 6889 \le C_{81,83} \le 3.5 \times 6889$$
$$\ldots$$
$$4.5 \times 1573 \le C_{81,88} \le 6.4 \times 1573$$
$$0.95 \times 1380 \le C_{87,91} \le 1.1 \times 1380$$
$$\ldots$$
$$0.95 \times 7960 \le C_{90,93} \le 1.1 \times 7960$$

Multiple inputs consumed in each output:

$$C_{t,91} = C_{87,91} + C_{88,91} + C_{89,91} + C_{90,91}$$
$$\ldots$$
$$C_{t,93} = C_{87,93} + C_{88,93} + C_{89,93} + C_{90,93}$$

Prior lower and upper bound on multiple inputs in each output:

$$0.95 \times 1380 \le C_{t,91} \le 1.10 \times 1380$$
$$\ldots$$
$$0.95 \times 7960 \le C_{t,93} \le 1.10 \times 7960$$

Solution

The solution of the goal programming problem gave the following two positive deviational variables, all others were zero:

$C_{81}^{-} = 10770$, and $C_{90}^{-} = 2610$

Thus, the reported industrial roundwood consumption in India was 10 770 thousand m^3, or 24 per cent less than the estimated consumption, and the reported recovered paper consumption was 2 610 thousand t, or 12 per cent less than the estimated. The reported consumption of mechanical pulp, chemical pulp, and other fiber pulp was the same as the estimated. The estimated industrial roundwood used in making sawnwood, panels and wood pulp was (in 1000 m^3):

$C_{81,83}$	$C_{81,84}$	$C_{81,85}$	$C_{81,86}$	$C_{81,87}$	$C_{81,88}$
24 112	8730	43	944	1389	10 067

and the estimated amounts of the various fibers used in making paper and paperboard were (in 1000 t):

$C_{87,91}$	$C_{88,91}$	$C_{88,93}$	$C_{89,93}$	$C_{90,92}$	$C_{90,93}$
488	823	1593	2014	4190	3954

Which, given the reported production in Table B1 gave the following estimated input–output coefficients:

$r_{81,83}$ m^3/m^3	$r_{81,84}$ m^3/m^3	$r_{81,85}$ m^3/m^3	$r_{81,86}$ m^3/m^3	$r_{81,87}$ m^3/t	$r_{81,88}$ m^3/t	$r_{87,91}$ t/t	$r_{88,91}$ t/t	$r_{88,93}$ t/t	$r_{89,93}$ t/t	$r_{90,92}$ t/t	$r_{90,93}$ t/t
3.5	3.1	1.8	3.3	2.9	6.4	0.35	0.60	0.20	0.25	0.95	0.50

Table B1 FAOSTAT statistics for India, averaged over 2013, 2014 and 2015

Product code	Product	Consumption[1] C_m^0	Production Q_p^0
		(1000 m^3)	(1000 m^3)
81	Industrial roundwood	56 054	
83	Sawnwood		6889
84	Veneer & plywood		2816
85	Particleboard		24
86	Fiberboard		286
		(1000 t)	(1000 t)
87	Mechanical pulp	488	479
88	Chemical pulp	2416	1573
89	Other fiber pulp	2014	
90	Recovered paper	5534	
91	Newsprint		1380
92	Printing & writing Paper		4411
93	Other paper & paperboard		7960

[1]Production+imports-exports.

Table B2 Upper and lower bounds on input–output coefficients

Output (*p*)	83	84	85	86	87	88	91	92	93
Input(*m*)	Upper bound								
81	3.5	3.1	1.8	3.3	2.9	6.4			
87							1.10	1.10	1.10
88							1.10	1.10	1.10
89							1.10	1.10	1.10
90							1.10	1.10	1.10
Total (*t*)							1.10	1.10	1.10
	Lower bound								
81	1.4	1.5	1.2	1.5	1.2	4.5			
87							0.00	0.00	0.00
88							0.00	0.00	0.00
89							0.00	0.00	0.00
90							0.00	0.00	0.00
Total (*t*)							0.95	0.95	0.95