Forestry An International Journal of Forest Research

Institute of Chartered Foresters

Forestry 2017; **90**, 47–57, doi:10.1093/forestry/cpw062
Advance Access publication 8 December 2016

Impact of Brexit on the forest products industry of the United Kingdom and the rest of the world

Craig M. T. Johnston and Joseph Buongiorno

University of Wisconsin-Madison, Forest and Wildlife Ecology, Madison, USA

Received 28 September 2016

The Global Forest Products Model was applied to forecast the effect of Brexit on the global forest products industry to 2030 under two scenarios: an optimistic and pessimistic future storyline regarding the potential economic effect of Brexit. The forecasts integrated a range of gross domestic product growth rates using an average of the optimistic and pessimistic projections from recent reports. According to the results, Brexit caused a sustained modest decline in UK demand for wood products through 2030. The consumption of sawnwood in Britain was 1.0–2.1% lower by 2030, 2.9–6.1% lower for wood-based panels and 1.9–4.1% lower for paper and paperboard. With Brexit, the UK net trade deficit in sawnwood decreased by 4.8–9.9% by 2030, 4.4–9.1% for wood-based panel and 5.5–10.8% for paper and paperboard. The effects on industrial roundwood consumption and production within the UK were negligible. Both scenarios had a modest adverse effect on the global market for wood products. The consequences of Brexit were mostly within Europe and driven predominantly by reduced consumption within the UK itself. While the effect was greater under the pessimistic scenario, the overall impact on the global wood products industry was small, and it had no discernable effect on prices.

Introduction

On 23 June 2016, the UK voted to end its membership in the European Union (EU), creating widespread uncertainty in global financial markets; the S&P 500 fell 3.59% in the US, the FTSE 100 fell 3.15% in Britain, and the DAX index fell 6.82% in Germany. These bearish reactions reflect larger concerns that may contribute to reduced growth of the UK economy including increased uncertainty about future levels of household income, deteriorating terms of trade, and a discouragement to invest among UK firms. Together, these factors may lead to reduced consumption, production and trade within the British economy. Furthermore, Britain's exit means the EU loses economic power as Britain represented 16.2% of the EU's economy in 2015; an important implication as the EU will likely remain Britain's most important trading partner.

The forest products industry may be vulnerable to such developments. Wood products are normal goods, such that declines in national income negatively affect consumption (UNECE, 2003; Michinika et al., 2011; Buongiorno, 2015). Furthermore, the industry revolves in a complex market, as wood products are interlinked and traded internationally to capture comparative advantage. As a result, economic shocks within the EU are likely distributed across wood product markets and regions, as observed in recent renewable energy policies within the EU and the UK (Johnston and van Kooten, 2016). Nonetheless, the impact on the forest products industry has the potential to be significant as the UK relies heavily on imports. In 2014, the UK had a net trade deficit of $2.2 billion in lumber, $0.8 billion in wood pulp and $1.4 billion in wood based panels (FAO, 2016). Declining consumption and eroding terms of trade will affect the UK wood products industry, and may have implications for international markets.

While many believe Brexit will negatively impact the British economy, the magnitude of this effect remains unclear. A number of sources have provided short- and long-term forecasts of the effect of Brexit on the UK's gross domestic product (GDP) (Table 1) with great speculation surrounding the UK's ability to negotiate trade agreements. A common pattern among the studies highlighted in Table 1 is the adoption of optimistic and pessimistic scenarios to describe the economic effect of Brexit. The optimistic scenario often assumes that the UK and the EU will continue to enjoy free trade and that Brexit does not create additional tariff barriers. In the pessimistic scenarios, it is commonly supposed that the UK fails to negotiate a new trade agreement with the EU, leading to increased tariffs on imports, higher non-tariff barriers to trade (i.e. changing regulations, border controls), and minimal integration between the UK and EU in future trade policy.

While much attention has been placed on projecting the potential effect of Brexit on UK income, little is known about how this may impact the wood products industry. Therefore, this paper attempted to determine, other things being equal, the consequences for the forest sector of the UK's departure from the EU. As there is a large amount of uncertainty surrounding the degree to which the UK and other economies will be affected, this study utilized available projections of GDP to reflect two very different future Brexit storylines. Then, a forest

Table 1 Projected impacts of Brexit on Britain's economy

Source (Date)	Effect on GDP, %			
	Short run		Long run	
Institute of Economic Affairs (2015)	+1.10 to −2.60			
Centre for Economic Performance, LSE (2016)	−1.30 to −2.60		−6.30 to −9.50	
The Economist Intelligence Unit (2016)	−3.00	*by 2017*	−6.50	
	−4.00	*by 2018*		
KPMG (2016)	−0.50 to −1.50		−4.00 to −6.00	*by 2031*
National Institute of Economic and Social Research (2004)			−1.90 to −7.80	*by 2030*
OECD (2016)			−2.70 to −7.50	*by 2030*
Open Europe (2016)			+1.60 to −2.20	
Oxford Economics (2016)			−0.10 to −3.90	
PwC (2016)			−3.00 to −5.50	*by 2020*
World Economic Outlook, IMF (2016)	−0.20	*by 2016*		
	−1.08	*by 2017*		
UK Treasury (2016)	−3.60 to −6.00		−3.80 to −7.50	
Average	−1.30 to −2.50		−2.97 to −6.27	

sector model was used to evaluate their consequences for wood industries, and thus inform decision makers concerned with the future of this sector in and outside the UK.

The next section describes the methodological framework including a discussion of the assumptions regarding future rates of GDP due to Brexit. This is followed by results showing the expected least and worst effects of Brexit up to 2030. While the effects were modest in some UK industries, they appeared negligible in the rest of the world.

Methods and data

The Global Forest Products Model

The Global Forest Products Model is a dynamic spatial price equilibrium model for 180 countries, and 14 forest commodity groups covering fuelwood, industrial roundwood, sawnwood, wood-based panels, pulp, newsprint, paper and paperboard. The GFPM produces forecasts of forest area and stock, and related global production, consumption, trade and prices of products. The model is recursive and solves each year a spatial equilibrium among all countries by maximizing quasi-welfare: the value of end products minus the cost of production and transportation (Samuelson, 1952; Takayama and Judge, 1971). Successive yearly equilibria are linked dynamically to reflect demographic and economic growth, and changes in forest area and stock (see Appendix) (For more information on the model structure and several applications refer to Buongiorno et al. 2003. The current (2016) version of the model, together with software, data and documentation are available from http://labs.russell.wisc.edu/buongiorno/welcome/gfpm/).

The data of the GFPM come from various sources. The main database for prices, production, import and export data is at the Food and Agriculture Organization of the United Nations (FAOSTAT; FAO, 2016). Buongiorno and Zhu (2016) describe how the input–output coefficients and manufacturing costs were calibrated with this data for the base year 2013. Technical change affecting these coefficients were predicted as in Buongiorno and Zhu (2015). The GDP and price elasticities of demand for end products, which play a critical role in this study, are in Table 2. The elasticities of wood supply are based on Turner et al. (2006). The equations for changes in forest area and forest stock were estimated with data from FAO (2010) as in Buongiorno (2014). The GDP and population scenarios up to 2030, without Brexit, were based on the IPCC scenario A1B (Nakicenovic et al., 2000), modified for the purpose of the United States Forest Service 2010 RPA Assessment (USDA Forest Service, 2012).

Table 2 GDP and price elasticity of demand used in the GFPM projections (*source*: Buongiorno, 2015).

Commodity	Income level	Elasticity			
		GDP	SE	Price	SE
Sawnwood	Low[1] or high	0.24	0.1*	−0.17	0.05**
Veneer & plywood	Low	0.72	0.11**	−0.33	0.05**
	High	0.72	0.11**	−0.61	0.12**
Particleboard	Low or high	0.59	0.09**	−0.51	0.05**
Fiberboard	Low or high	0.92	0.12**	−0.54	0.06**
Newsprint	Low	0.42	0.06**	−0.25	0.05**
	High	0.39	0.17*	−0.04	0.13
Printing & writing	Low or high	0.59	0.08**	−0.53	0.1**
Other paper & paperboard	Low or high	0.4	0.08**	−0.45	0.06**

SE, standard error; * and ** are significant at 5% and 1%, respectively.
[1]Less than $US 15 000/capita at 2013 prices.

Consequence of Brexit for GDP

The effect of Brexit was simulated with the GFPM via two storylines (optimistic and pessimistic future scenarios) concerning the effect of Brexit on GDP growth rates. Table 1 highlights a number of short- and long-term projections for this effect on UK's GDP. Among the most optimistic short-run scenarios are those of the Institute of Economic Affairs (IEA), who project a net positive impact on UK GDP of 1.1% within 1–3 years of exit (IEA, 2015). This projection relies on the UK securing access to the European Free Trade Association, sustained terms of trade, and a favourable exit agreement with the EU. However, the IEA acknowledges Brexit is likely to have a more modest effect on the UK economy. On the pessimistic side, the UK Treasury (2016) provides a short-run projection of the Brexit impact on the UK's economy of −6.0%. Here, the UK's departure is assumed to result in a significant economic shock with high unemployment, and adverse effects on wages, inflation, housing values

and access to capital. In all these projections the effects of Brexit on the UK economy would be rapid, with most of the adverse economic shock occurring within a few years after the departure from the EU.

Still, several studies suggest that these early effects may continue for many years. One of the most optimistic long-run scenarios is that of Open Europe (2016), who project that long-run GDP in the UK could rise by 1.6% due to the negotiation of free trade agreements, and liberal immigration policy and deregulation allowing free labour mobility and an elimination of onerous laws. This scenario assumes an almost utopian exit from the EU market, so much so that the authors admit it is more likely that the UK's economy will in fact fall by 0.5–1.5%. The Centre for Economic Performance at the London School of Economics provides an even more pessimistic scenario where Brexit results in a −9.5% impact on long-run GDP in the UK (CEP, 2016), due to reduced trade and productivity in the UK, with a failure to secure free trade agreements in the long run.

Given the wide range of projections, we summarized the effects of Brexit on UK GDP into an optimistic and a pessimistic scenario. Using the average projections in Table 1, the optimistic scenario assumed that Brexit reduced UK GDP by 1.3% in the short run, and 3.0% in the long run. In the pessimistic scenario UK GDP fell by a greater amount; 2.5% in the short run, and 6.3% in the long run. These two scenarios reflected the range of possibilities regarding the evolution of new trade agreements, non-tariff barriers to trade, and other economic shocks associated with Brexit. These numbers were converted to annual rates for use in the GFPM.

For other countries, the Centre for Economic Performance (CEP, 2016) projects that Brexit will adversely affect their GDP, largely due to their trade with the UK. According to Figure 1, Brexit will result in a 0.1–0.3% reduction in GDP across other current EU countries post- Brexit, although concentrated in Ireland, Belgium and the Netherlands. Meanwhile, the effect on income may be neutral or even slightly positive in some non-EU countries. Reflecting the uncertainty of these forecasts the CEP also provides, in addition to the most likely case, the optimistic and pessimistic projections of the macroeconomic (GDP) effect of Brexit (Figure 1) which were adopted in this study for countries other than the UK.

Results

The GFPM was used to forecast the global forest products industry to 2030 under the base GDP scenario, and the optimistic and pessimistic scenarios. The main effect of changes in GDP was to shift the demand for wood products (appendix equation A3) to the left or to the right. The corresponding change in GDP per capita also affected forest area (appendix equation A8), but the effect was negligible. Through the equilibrium process, the demand shift affected consumption, production and prices of industrial roundwood, sawnwood, wood-based panels and paper and paperboard. For all products the price effects were negligible.

Effects on sawnwood production, consumption and trade

The consequences of Brexit on global sawnwood production and consumption are in Table 3, highlighting a global market reduction of ~100 000–220 000 m^3 by 2030. This adverse effect was due largely to the decline in sawnwood consumption in the UK, which was 1.0% lower in 2030 under the optimistic future storyline, and 2.1% lower under the pessimistic (Figure 2a). representing 84–87% of total European decline. In conjunction with decreased domestic demand, the UK net trade deficit in sawnwood decreased by 4.8% under the optimistic storyline, and 9.9% under the pessimistic storyline by 2030, reflecting mostly lower imports (Figure 2b). While the attendant fall in global consumption was larger under the pessimistic scenario, it represented only 0.05% of global sawnwood market. The effects on significant EU trading partners like Ireland, the Netherlands and Belgium, and on the rest of the world was negligible.

The effect on sawnwood production was distributed across developed and developing countries, but principally in the UK where production rose by 123 000–256 000 m^3, and coupled

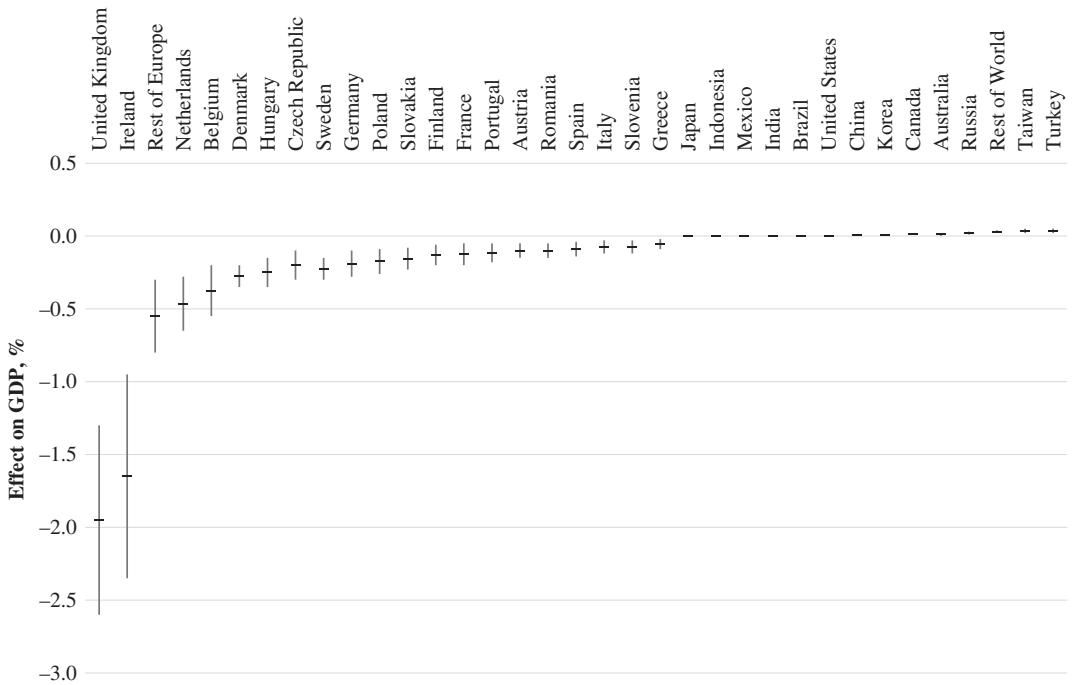

Figure 1 Projected static effect of Brexit on the GDP of selected countries (*source*: CEP, 2016).

Table 3 Consequences of Brexit on sawnwood by region and selected countries in 2030

	Consumption ('000 m^3)			Production ('000 m^3)		
		Brexit effect			Brexit effect	
	Baseline	*Optimistic*	*Pessimistic*	Baseline	*Optimistic*	*Pessimistic*
Europe	114 841	−111	−244	197 774	73	143
UK	9684	−97	−204	5445	123	256
Russia	14 516	1	2	31 178	18	28
EU-27	82 340	−15	−43	150 204	−49	−101
Ireland	418	−1	−2	1560	0	1
Netherlands	2378	−2	−4	–	0	0
Belgium	2454	−1	−3	2394	−1	−3
Denmark	2044	−1	−1	–	0	0
Hungary	523	0	0	168	−1	1
Czech Republic	3628	−1	−2	5274	−15	−32
Sweden	5522	−2	−5	28 478	8	18
Germany	19 747	−4	−11	32 951	−5	−11
Slovakia	1466	0	−1	1994	−6	−12
Finland	3777	0	−2	16 912	24	61
France	10 043	−1	−5	9685	−1	−5
Portugal	537	0	0	922	1	−1
Austria	5614	−1	−2	15 238	−17	−36
Romania	2807	0	−1	9846	−9	−19
Spain	2796	0	−1	2397	−7	−18
Italy	6027	−1	−2	3694	−5	−10
Slovenia	684	0	0	1748	−2	−4
Greece	354	0	0	209	0	−1
Poland	5678	−1	−3	5727	−1	−3
America's	147 713	6	14	174 231	−39	−78
Canada	17 061	1	4	47 372	−24	−50
USA	91 633	4	7	88 051	−2	−5
Mexico	5271	0	1	2505	−7	−13
Brazil	16 775	1	1	17 709	1	1
Asia	196 781	3	9	99 932	−109	−232
China	110 245	0	0	38 873	0	0
India	9962	0	1	8586	0	1
Japan	17 522	1	2	9189	−73	−156
Indonesia	4612	0	0	4965	0	0
South Korea	4815	0	0	4078	−3	−6
Turkey	8924	0	2	8607	0	2
Oceania	7836	0	1	9514	−20	−44
Australia	5255	0	0	3889	−8	−18
Developed, all	258 971	−104	−230	354 193	−48	−114
Developing, all	228 344	4	10	137 423	−53	−107
World	487 315	−100	−220	491 617	−101	−221

World production may differ from consumption due to round off errors.

with a fall in consumption, led to the improvement of EU net trade in sawnwood (Figure 2b). Still, the impact of Brexit on global sawnwood production was a mere 0.02–0.05% reduction under the optimistic and pessimistic scenarios, alike. Production in Britain was only 1.1% of global sawnwood production, and thus had a small global impact. Countries within the EU where Brexit had the highest GDP impact (i.e. Ireland, Netherlands, Belgium), experienced negligible changes in consumption or production of sawnwood. Production in Japan fell by 73 000–156 000 m^3 as a result of reduced global demand.

Effects on wood-based panel production, consumption and trade

Table 4 summarizes the consequences of Brexit on the global wood-based panel production and consumption p. The

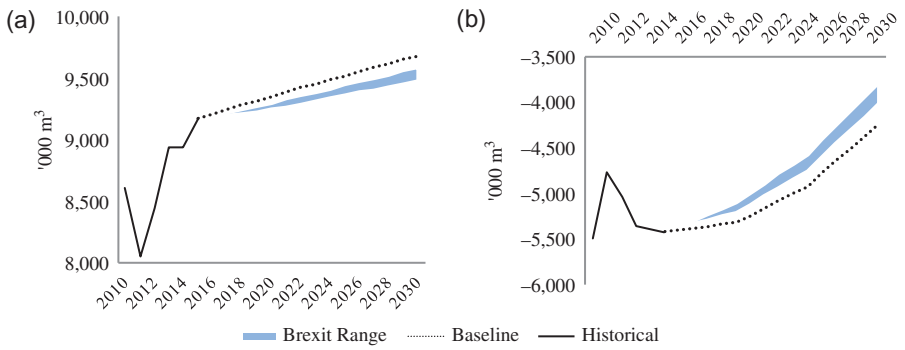

Figure 2 Projected effect of Brexit on UK consumption and net trade of sawnwood. (a) Consumption, (b) Net Trade.

Table 4 Consequences of Brexit on wood-based panels by region and selected countries in 2030.

	Consumption ('000 m^3)			Production ('000 m^3)		
		Brexit effect			Brexit effect	
	Baseline	*Optimistic*	*Pessimistic*	Baseline	*Optimistic*	*Pessimistic*
Europe	99 861	–212	–462	123 838	–149	–315
UK	6071	–178	–369	4437	–106	–221
Russia	21 039	2	7	20 976	–6	–16
EU-27	64 336	–37	–101	90 722	–33	–71
Ireland	396	–3	–7	1107	0	–1
Netherlands	1251	–2	–6	272	0	0
Belgium	2497	–3	–9	4118	7	18
Denmark	1113	–1	–2	937	–1	–2
Hungary	940	–1	–2	1042	–1	–2
Czech Republic	1170	–1	–2	2100	–2	–6
Sweden	1526	–2	–3	1171	–1	–2
Germany	12 364	–8	–23	20 791	–5	–7
Slovakia	1481	–1	–2	1517	–1	–2
Finland	702	0	–1	2412	–1	–2
France	5430	–2	–7	5918	–4	–11
Portugal	1049	0	–1	3192	0	4
Austria	1340	0	–1	6074	–8	–15
Romania	4448	–2	–4	5611	–6	–15
Spain	2317	–1	–2	3830	–1	0
Italy	5286	–1	–4	5139	–1	–4
Slovenia	411	0	0	567	0	–1
Greece	434	0	0	517	0	0
Poland	15 570	–10	–25	18 187	–4	–10
America's	87 499	5	11	93 999	–4	–27
Canada	9458	1	3	16 818	–3	–10
USA	46 580	3	5	44 939	1	0
Mexico	3816	0	1	2730	1	1
Brazil	17 266	1	2	20 480	–1	–13
Asia	444 133	7	15	421 159	–42	–89
China	352 526	0	0	349 781	0	0
India	10 055	1	1	8117	–3	–8
Japan	10 094	1	1	7435	–4	–8
Indonesia	9778	1	1	10 349	–1	–4
South Korea	9351	1	2	6153	–6	–11
Turkey	14 559	3	6	14 570	3	6
Oceania	3969	1	1	4773	–1	–3
Australia	2320	0	1	1755	–1	–1
Developed, all	178 353	–207	–450	199 772	–159	–335
Developing, all	466 483	8	16	449 910	–39	–99
World	644 835	–198	–435	649 682	–198	–434

optimistic and pessimistic scenarios imply a small decline in global panel markets of 198 000–435 000 m^3 (0.03–0.07%) by 2030, localized mostly within the UK, where consumption fell by 2.9–6.1% by 2030 (Figure 3a), and production by 2.4–5.0% leading to an improvement in UK net trade of 4.4–9.1% depending on the scenario (Figure 3b).

Modest effects in wood-based panel consumption were observed for some EU countries like Germany (8000–23 000 m^3) and Poland (10 000–25 000 m^3). While Brexit had the highest GDP impact, after the UK, in Ireland, the Netherlands and Belgium, consumption and production of wood-based panels was modestly affected through 2030 as these countries have relatively small panel markets. Outside the EU, 25% of the decline in production was in developing countries under the pessimistic scenario, localized in Asian-Pacific countries.

Effects on paper and paperboard production, consumption and trade

The main impact of Brexit on paper and paperboard markets occurred in the UK where consumption was 1.9–4.1% lower by 2030 (Figure 4a). Correspondingly, net trade improved by 5.5–10.8% depending on the scenario (Figure 4b). As 87–90% of the reduction in global paper and paperboard consumption was in the UK, the global impact was small, a 0.04–0.08% reduction by 2030 (Table 5). Consumption in non-European countries experienced minor increases, offsetting some of the decline projected in Britain. Overall, developed countries reduced their consumption between 233 000 and 502 000 m^3 by 2030 as a result of the optimistic and pessimistic future Brexit storylines adopted in this study, respectively. Consumption in developed countries remained relatively unaffected.

The Brexit-induced changes in paper and paperboard production were more evenly distributed across countries than changes in consumption. Although most of the decrease in consumption was in Europe, the decrease in European production was only 41% of the decrease in global production. The US contributed a further 40% to the decline in global production, while other markets were more modestly affected. Countries within the EU where Brexit had the highest GDP impact (i.e. Ireland, Netherlands, Belgium), experienced negligible changes in consumption or production of paper and paperboard. Production in China and the US fell by 31 000–68 000 m^3 and 93 000–196 000 m^3, respectively, as a result of reduced global demand.

Effects on industrial roundwood production, consumption and trade

In contrast with sawnwood, panels and paper and paperboard, the effect of Brexit on industrial roundwood consumption and

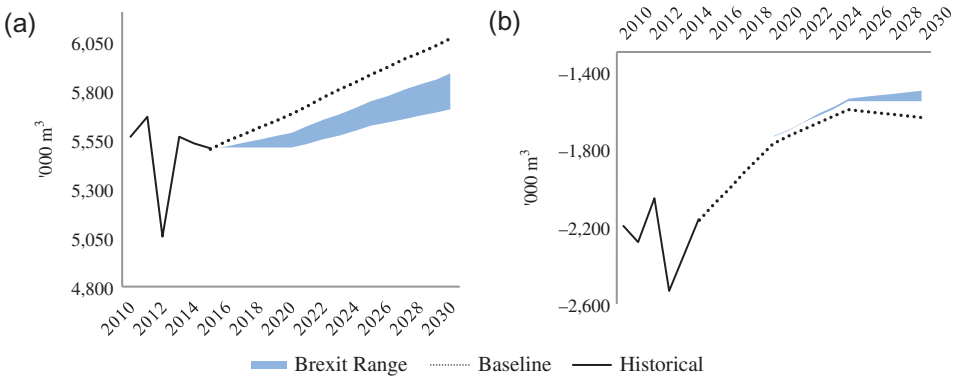

Figure 3 Projected effect of Brexit on UK consumption and net trade of wood-based. (a) Consumption, (b) Net Trade.

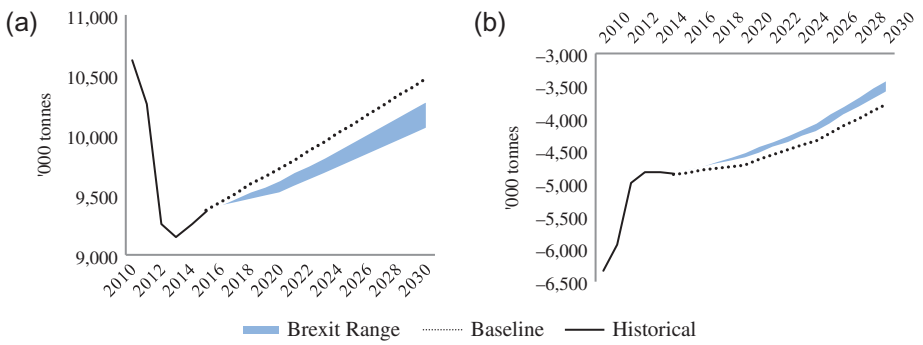

Figure 4 Projected effect of Brexit on UK consumption and net trade of paper and paperboard. (a) Consumption, (b) Net Trade.

Table 5 Consequences of Brexit on paper and paperboard by region and selected countries in 2030

	Consumption ('000 m^3)			Production ('000 m^3)		
		Brexit effect			Brexit effect	
	Baseline	*Optimistic*	*Pessimistic*	Baseline	*Optimistic*	*Pessimistic*
Europe	108 297	−237	−512	119 401	−73	−160
UK	10 488	−204	−426	6730	−25	−52
Russia	9652	1	2	10 386	0	1
EU-27	82 316	−33	−88	97 129	−48	−108
Ireland	560	−2	−6	–	0	0
Netherlands	3586	−4	−10	4421	−8	−15
Belgium	2970	−3	−8	2732	−2	−6
Denmark	1213	−1	−2	698	0	−1
Hungary	1199	−1	−2	935	−1	−3
Czech Republic	1963	−1	−2	488	0	−1
Sweden	1959	−1	−3	7019	−2	−4
Germany	21 468	−9	−25	20 553	−6	−13
Slovakia	1009	0	−1	698	0	−1
Finland	1278	0	−1	9016	−2	−7
France	9977	−3	−9	11 576	−6	−12
Portugal	1286	0	−1	2806	−6	−11
Austria	2326	0	−1	7416	−5	−10
Romania	1219	0	−1	382	−1	−1
Spain	7101	−1	−4	7468	−1	−2
Italy	10 802	−2	−5	12 771	−8	−17
Slovenia	691	0	0	1216	−1	−3
Greece	1071	0	0	226	0	0
Poland	8056	−3	−8	5678	1	0
America's	124 468	4	9	129 496	−111	−234
Canada	6142	0	1	12 972	−8	−17
USA	80 973	3	6	83 997	−93	−196
Mexico	10 712	0	1	9358	−1	−3
Brazil	13 573	0	1	15 920	−7	−16
Asia	293 851	5	12	287 200	−40	−88
China	172 049	2	4	180 620	−31	−68
India	22 352	1	1	18 442	1	1
Japan	29 407	0	1	27 654	−1	−4
Indonesia	12 043	1	2	17 617	1	2
South Korea	12 236	0	1	14 200	0	−1
Turkey	6994	1	1	4897	−2	−5
Oceania	5174	0	1	4232	−3	−6
Australia	4213	0	1	3474	−3	−6
Developed, all	235 589	−233	−502	252 650	−177	−383
Developing, all	307 739	6	14	293 707	−49	−105
World	543 328	−227	−488	546 357	−226	−488

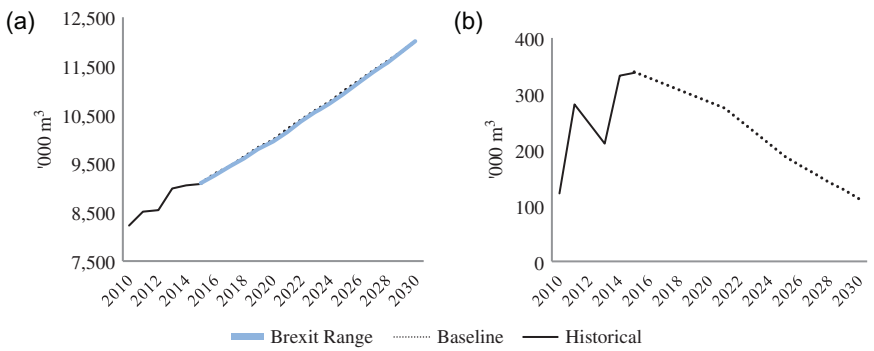

Figure 5 Projected effect of Brexit on UK consumption and net trade of roundwood. (a) Consumption, (b) Net Trade.

net trade in the UK was negligible (Figure 5a,b). The demand for industrial roundwood derives from the demand for wood associated with the manufacturing of end products. While production of sawnwood rose in Britain, it was offset by reductions in panel and paper manufacturing, translating to negligible changes in the domestic supply of industrial roundwood.

There was only a small effect of Brexit on the global consumption of industrial roundwood (Table 6), which fell by 598 000–1 291 000 m^3 by 2030 depending on the scenario, representing 0.03–0.05% of global consumption. The largest impact was in Japan, the EU, and the US who contribute ~16, 17 and 24 per cent to the total decline in consumption. Meanwhile the production of industrial roundwood decreased mostly in Canada, the US, Russia and Asia. Net trade in many of these countries was relatively unaffected as consumption and production fell at a similar pace, with the exception of Asia where the fall in consumption was more than the fall in production, resulting in improved trade.

Table 6 Consequences of Brexit on industrial roundwood by region and selected countries to 2030

	Consumption ('000 m^3)			Production ('000 m^3)		
		Brexit Effect			Brexit Effect	
	Baseline	*Optimistic*	*Pessimistic*	Baseline	*Optimistic*	*Pessimistic*
Europe	693 510	−97	−219	739 981	−227	−476
UK	12 015	−3	−6	12 128	−3	−6
Russia	178 586	37	51	216 406	−88	−183
EU-27	471 329	−102	−204	453 537	−112	−237
Ireland	3637	0	0	3833	−1	−2
Netherlands	449	−1	−2	1275	−1	−1
Belgium	14 125	10	26	4851	−1	−3
Denmark	1432	−2	−3	1711	−2	−3
Hungary	2785	−3	−1	3968	−1	−2
Czech Republic	14 132	−30	−67	19 874	−5	−14
Sweden	83 016	5	12	78 391	2	4
Germany	70 992	−15	−30	67 669	−16	−30
Slovakia	8036	−11	−28	11 508	−4	−9
Finland	72 415	54	136	61 102	−11	−30
France	24 644	−12	−24	38 541	−12	−24
Portugal	17 952	−1	−4	12 177	−1	−2
Austria	33 989	−34	−71	16 150	−7	−14
Romania	15 868	−14	−33	14 578	−7	−14
Spain	13 100	−12	−27	18 827	−11	−22
Italy	11 038	−8	−17	3505	−1	−2
Slovenia	2681	−2	−5	4399	−2	−4
Greece	1052	−1	−1	781	−1	−1
Poland	54 513	−6	−21	48 810	−17	−31
America's	830 223	−259	−570	886 791	−268	−593
Canada	187 764	−66	−155	174 671	−66	−155
USA	404 209	−140	−303	456 359	−140	−303
Mexico	7239	−6	−11	7237	−6	−11
Brazil	156 858	−38	−80	160 063	−38	−80
Asia	754 967	−200	−427	607 204	−64	−138
China	450 157	0	0	329 762	0	0
India	65 559	−8	−17	52 238	−8	−17
Japan	46 213	−100	−212	23 736	−9	−16
Indonesia	71 057	−15	−32	72 060	−15	−32
South Korea	15 544	−10	−23	9105	−3	−6
Turkey	32 115	3	8	24 329	−9	−17
Oceania	28 555	−32	−64	67 784	−23	−54
Australia	10 775	−13	−28	27 143	−12	−24
Developed, all	1 377 435	−436	−952	1 478 363	−471	−1014
Developing, all	994 780	−162	−339	896 847	−127	−277
World	2 372 215	−598	−1291	2 375 210	−598	−1291

Conclusion

The Global Forest Products Model was applied to forecast the effect of Brexit on forest industries to 2030. The projections reflected an optimistic and a pessimistic scenario based on recent data concerning the effect of Brexit on the GDP of the UK, the EU and other countries. While the results are sensitive to the assumed effect of Brexit, both scenarios had a modest adverse effect on the global market for final wood products. The main consequences were for the UK, and secondarily for Europe.

The optimistic and pessimistic scenario's adopted in this study reflect the possible range of economic growth in the aftermath of Brexit. Still, the uncertainty may even be greater for various reasons. First, the cost of capital may rise in the short run, as the uncertainty created through the UK's departure from the EU calls for a higher risk premium on lending. As a result, firms will face a more difficult time acquiring capital, which will reduce investment.

Second, Brexit uncertainty may encourage the sale of UK assets, putting downward pressure on the pound. One consequence would be higher import costs, leading to further inflation. The degree to which the rise in inflation is passed through to consumers will drive reductions in consumption patterns, and the degree to which profit margins are squeezed will determine the degree of job losses within the UK. The Bank of England might attempt to counteract any inflationary pressure caused by Brexit, which may further disrupt capital markets. Meanwhile, the depreciation of the pound will cause imports to decline allowing the external balance to improve, mitigating the depth of the GDP contraction. The extent to which these factors play out in the coming years remains unknown.

Third, the ability for the UK to negotiate trade deals with important trading partners will drive the magnitude of the economic effect of Brexit. There are many possible scenarios for the UK's future position, ranging from preserving its existing trade relationship with the EU to a failure to reach agreements and a reversion to World Trade Organization tariffs.

Fourth, it has been argued that UK residents born outside of Britain have higher productivity and labour market participation, and that restricted labour mobility associated with Brexit could put upward pressure on low-skilled wages (KPMG, 2016). As a result, it may become more difficult to match jobs and workers in some industries, and could reduce long-term productivity. The degree to which these factors affect the economy relies on the extent that Brexit restricts labour mobility.

The projections presented here depend strongly on the modelling structure of the GFPM and the quality of the underlying data. Although the model mimics the general trends of historical data series' reasonably well, the errors increase with the level of disaggregation by product or region, and with the length of the forecast (Buongiorno et al., 2001). The GFPM provides a comprehensive representation of the forest sector, but the data on which it, and similar models, are based are often inaccurate. Furthermore, the model parameters, such as the supply and demand elasticities are also subject to error. The fundamental theory of trade on which it relies (pure competition in international markets) can also only be a rough approximation of the complex reality of international trade. Although, by construction, the model fits very accurately the observations in the base year, it can only approximate out of sample projections, leaving much work to be done to improve the basic data and the underlying assumptions of the model.

Future work may wish to consider the degree in which Britain continues to pursue EU policies. For example, the UK currently subsidizes energy produced from biomass in order to comply with EU's legislated renewable energy targets set out for 2020 and 2030. As a result, the UK has emerged as one of the world's largest consumers of wood pellets, with over 5 million m^3 consumed 2014. And, 93% of wood pellet consumption in the UK come from outside its borders, primarily from North America. The extent to which the UK will continue to employ strong subsidies for bioenergy has the potential to disrupt international wood product markets (Johnston & van Kooten 2016).

Acknowledgements

The authors gratefully acknowledge the assistance of Shushuai Zhu in calibrating the GFPM model used in this study.

Conflict of interest statement

None declared.

Funding

The research leading to this paper was supported in part by joint venture agreements between the University of Wisconsin and the USDA Forest Service Southern Forest Research Station (12-JV-11330143-065) and (16-JV-11330143-039), in cooperation with project leader Jeff Prestemon.

References

Buongiorno, J. 2014 Global modeling to predict wood production and prices: The GFPM approach. *Forestry* **88**, 291–303.

Buongiorno, J. 2015 Income and time dependence of forest product demand elasticities and implications for forecasting. *Silva Fenn.* **49** (5), 1395.

Buongiorno, J., Liu, C.S. and Turner, J. 2001 Estimating international wood and fiber utilization accounts in the presence of measurement errors. *J. For. Econ.* **7** (2), 101–124.

Buongiorno, J., Zhu, S., Zhang, D., Turner, J. and Tomberlin, D. 2003 The Global Forest Products Model: Structure, Estimation, and Applications. Academic Press/Elsevier.

Buongiorno, J. and Zhu, S. 2015 Technical change in forest sector models: the global forest products model approach. *Scand. J. For. Res.* **30** (1), 30–48.

Buongiorno, J. and Zhu, S., 2016 Calibrating and updating the Global Forest Products Model (GFPM version 2016 with BPMDP). Staff paper #86, Department of Forest and Wildlife Ecology, University of Wisconsin, Madison. 29p. Available at: http://labs.russell.wisc.edu/buongiorno/welcome/gfpm/.

CEP (Centre for Economic Performance), 2016 Brexit 2016: Policy analysis from the Centre for Economic Performance. The London School of Economics and Political Science. http://cep.lse.ac.uk/BREXIT (accessed on 4 August, 2016).

EIU (The Economist Intelligence Unit), 2016 Out and down: Mapping the impact of Brexit. The Economist. http://www.eiu.com/public/topical_report.aspx?campaignid=Brexit (accessed on 8 August, 2016).

FAO (Food and Agriculture Organization of the United Nations), 2010 Global forest resources assessment. FAO Forestry Paper 163, Food and Agriculture Organization of the United Nations, Rome. pp. 340.

FAO (Food and Agriculture Organization of the United Nations), 2016 FAOSTAT Forestry Data 1961–2013. Food and Agriculture Organization of the United Nations, Rome. http://faostat.fao.org/site/630/default.aspx (accessed on 18 August, 2016).

IEA (Institute of Economic Affairs), 2015. Brexit: Directions for Britain outside the EU. https://iea.org.uk/publications/research/brexit-directions-for-britain-outside-the-eu (accessed on 3 August, 2016).

Johnston, C.M.T. and van Kooten, G.C. 2016 Global trade impacts of increasing Europe's bioenergy demand. *J. For. Econ.* **23**, 27–44.

KPMG, 2016. Brexit: The Economic Implications. https://home.kpmg.com/uk/en/home/insights/2016/05/brexit-the-economic-implications.html (accessed on 3 August, 2016).

Michinika, T., Tachibana, S. and Turner, J.A. 2011 Estimating price and income elasticities of demand for forest products: Cluster analysis used as a tool in grouping. *For. Policy Econ.* **13** (6), 435–445.

NIESR (National Institute of Economic and Social Research), 2004 The Macroeconomic Impact of UK Withdrawal from the EU. Authors: Pain, N. and G. Young. *Economic Modelling* 21: 387–408.

Nakicenovic N, Davidson O, Davis G, Grübler A, Kram T, Lebre La Rovere E, *et al*. 2000 Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, 599 pp. http://www.grida.no/climate/ipcc/emission/index.htm (accessed on 3 December, 2014).

Open Europe, 2016 Where enxt? A liberal, Free-market Guide to Brexit. http://openeurope.org.uk/intelligence/britain-and-the-eu/guide-to-brexit (accessed on 8 August, 2016).

OECD (Organisation for Economic Co-operation and Development), 2016 The Economic Consequences of Brexit: A Taxing Decision. http://www.oecd-ilibrary.org/economics/the-economic-consequences-of-brexit_5jm0lsvdkf6k-en (accessed on 8 August, 2016).

Oxford Economics, 2016 Assessing the Economic Implications of Brexit. http://www.oxfordeconomics.com/brexit (accessed on 7 August, 2016).

PwC, 2016 Leaving the EU: Implications for the UK Economy. http://www.pwc.co.uk/services/economics-policy/insights/implications-of-an-eu-exit-for-the-uk-economy.html (accessed on 8 August, 2016).

Samuelson, P.A. 1952 Spatial price equilibrium and linear programming. *Am. Econ. Rev.* **42**, 283–303.

Takayama, T. and Judge, G. 1971 *Spatial and Temporal Price and Allocation Models*. North-Holland, pp. p.528.

Turner, J.A., Buongiorno, J. and Zhu, S. 2006 An economic model of international wood supply, forest stock and forest area change. *Scand. J. For. Res.* **21**, 73–86.

UK Treasury, 2016 HM treasury analysis: The immediate economic impact of leaving the EU. https://www.gov.uk/government/publications/hm-treasury-analysis-the-immediate-economic-impact-of-leaving-the-eu (accessed on 21 August, 2016).

UNECE (United Nations Economic Commission for Europe), 2003 Modelling and projections of forest product demand, supply and trade in Europe. A study prepared for the European Forest Sector Outlook Study. https://www.unece.org/fileadmin/DAM/timber/docs/efsos/03-sept/dp-30.pdf (accessed on 2 August, 2016).

USDA (United States Department of Agriculture) Forest Service, 2012 Future of America's Forest and Rangelands: Forest Service 2010 Resources Planning Act Assessment. Gen. Tech. Rep. WO-87. Washington, DC. p 198.

World Economic Outlook, 2016 Uncertainty in the Aftermath of the U.K. Referendum. International Monetary Fund. http://www.imf.org/external/pubs/ft/weo/2016/update/02/ (accessed on 21 August, 2016).

Appendix

(Further detail on model structure, data and software are available at: http://labs.russell.wisc.edu/buongiorno/welcome/gfpm/)

The Global Forest Products Model is solved by maximizing the following objective:

max

$$Z = \sum_i \sum_k \int_0^{D_{ik}} P_{ik}(D_{ik})\,dD_{ik} - \sum_i \sum_k \int_0^{S_{ik}} P_{ik}(S_{ik})\,dS_{ik} - \sum_i \sum_k \int_0^{Y_{ik}} m_{ik}(y_{ik})\,dY_{ik} - \sum_i \sum_j \sum_k c_{ijk}\,T_{ijk}, \quad \text{(A1)}$$

where i,j = country, k = product, P = price in US dollars of constant value, D = final product demand, S = raw material supply, Y = quantity manufactured, m = manufacturing cost, T = quantity transported and c = cost of transportation, including tariff. All variables refer to a specific year. In making predictions, the period between successive equilibria may be multiple years.

End product demand

$$D_{ik} = D_{ik}^{*}\left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\delta_{ik}} \quad \text{(A2)}$$

where D^* = current consumption at last period's price, P_{-1} = last period's price and δ = price elasticity of demand.

D^* depends on last period's demand, and the growth of GDP in the country. In the base year, D^* is equal to the observed base-year consumption, and P_{-1} is equal to the observed base-year price.

Shifts of demand

$$D^* = D_{-1}\left(1 + \alpha_y g_y + \alpha_0\right) \quad \text{(A3)}$$

g_y = GDP periodic growth rate, α_y = elasticity with respect to GDP, α_0 = periodic trend.

Primary product supply

$$S_{ik} = S_{ik}^{*}\left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\lambda_{ik}} \quad \text{(A4)}$$

where S^* = current supply at last period's price, and λ = price elasticity of supply. As shown in the section on market dynamics, below, S^* depend on last period's supply, and on exogenous or endogenous supply shifters. In the base year, S^* is equal to the base-year supply, and P_{-1} is equal to the observed base-year price.

Industrial roundwood and fuelwood supply shifts

$$S^* = S_{-1}(1 + \beta_I g_I + \beta_a g_a) \text{ for } k = 1, n, f \quad \text{(A5)}$$

where g_I = periodic rate of change of forest stock (endogenous, see below), g_a = periodic rate of change of forest area and β = elasticity.

Waste paper and other fibre pulp supply shifts

$$S^* = S_{-1}\left(1 + \beta_y g_y\right) \quad \text{(A6)}$$

Changes in forest area and forest stock

$$A = (a + g_a)A_{-1} \quad \text{(A7)}$$

where A = forest area, and g_a = periodic rate of forest area change based on the period length and the annual rate of forest area change, g_{aa}, defined by:

$$g_{aa} = (a_0 + g_1 y')\, e^{a_2 y'}, \quad \text{(A8)}$$

where y' = income per capita, predicted from:

$$y' = (1 + g_{y'})\, y'_{-1} \quad \text{(A9)}$$

For each country, α_0 is calibrated so that in the base year the observed g_{aa} is equal to the g_{aa} predicted by (A7) given the income per capita y'.

Total wood drain from the forest

$$S_i = \left(S_{ir} + S_{in} + S_{if}\right)\mu_i \quad \text{(A10)}$$

r = industrial roundwood,
n = other industrial roundwood,
f = fuelwood,
$0 \le \theta \le 1$ = fraction of fuelwood that comes from the forest,
$\mu \ge 1$ = ratio of drain to harvest,
$S_i \le I_i$
I_i = forest stock.

Material balance

$$\sum_j T_{jik} + S_{ik} + Y_{ik} - D_{ik} - \sum_n a_{ikn} Y_{in} - \sum_j T_{ijk} = 0 \quad \forall\, i,\, k, \quad \text{(A11)}$$

where a_{ikn} = input of product k per unit of product n.

In addition, by products (also named secondary commodities), which result from the production of a (primary) manufactured commodity, such as sawmill residues that result from the production of sawnwood, satisfy the constraint:

$$Y_{il} - b_{ikl} Y_{il} = 0 \quad \forall\, i,\, k,\, l, \quad \text{(A12)}$$

where b_{ikl} is the amount of byproduct l that can be recovered per unit of manufactured commodity k.

For more detailed information on the model structure refer to Buongiorno et al. 2001, including the formulations of constraints related to trade inertia, prices, manufacturing costs, transport costs, market dynamics, linear approximations of certain constraints and annual allowable cut constraints.