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Gravity models of forest products trade: applications to forecasting and policy analysis

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To predict the value of trade between countries, a differential gravity model of bilateral trade flows was formulated and estimated with panel data from 2005 to 2014 for each of the commodity groups HS44 (wood and articles of wood), HS47 (pulp of wood, fibrous cellulosic material) and HS48 (paper and paperboard). The parameters were estimated with a large database by ordinary least squares, fixed-effects and random-effects methods. For the three commodity groups, the results were stable across methods. For HS44, exports were inelastic (0.33 ± 0.19) with respect to the gross domestic product (GDP) of exporters and elastic (1.95 ± 0.15) with the GDP of importers. For HS47, exports were elastic with respect to the exporters GDP (1.67 ± 0.55) and importers GDP (1.10 ± 0.36). Exports of HS48 were inelastic with the exporters GDP (0.81 ± 0.21) and elastic with respect to the importers (1.00 ± 0.14). For all three products, there were marked decreases in exports in 2009 and 2012 independent of GDP. The estimated elasticities were used to predict the growth rate of trade flows from 2015 to 2020 based on exogenous GDP projections of the International Monetary Fund. Another application investigated the effects of the Trans-Pacific Partnership agreement on the trade of forest products between the 12 member countries.

Keywords: international trade, forest products, gravity, econometrics, forecasting, policy analysis

Introduction

Several different theories of trade lead to an equation for trade flows analogous to Newton's gravitational law (Anderson, 1979; Feenstra *et al*., 2001; Anderson and van Wincoop, 2003; Santos Silva and Tenreyro, 2006). The economic gravity equation states that the trade flow between countries depends primarily on the size of the economy of the two countries, and on many secondary factors that are hard to measure. The equation has been applied to macroeconomic issues dealing with aggregate trade flows, for example, to investigate the effect of currency unions on trade (Rose, 2000; Frankel and Rose, 2002; Glick and Rose, 2002; Berger and Nitsch, 2008). It has also been applied to subsectors of the economy, such as agricultural commodities trade (Zahniser *et al*., 2002; Disdier and Marette, 2010; Peterson *et al*., 2013).

Fewer gravity models have been developed for the trade of forest products. Buongiorno *et al*. (1980) use a gravity model to represent the system of economic – and to some extent political – influences on the multilateral flow of tropical logs. Akyuz *et al*. (2010) show with similar methods the high degree of integration between Turkey and the European Union. Dai and Shen (2010) build empirical gravity equations of the trade of forest products between China and other Asia-Pacific countries. Buongiorno (2015) uses gravity models to argue that the introduction of the euro has had a strong positive effect on the European trade of wood and derivatives.

Given the potential of gravity models to predict detailed trade flows between countries in a relatively simple and yet rigorous manner, the objectives of this paper were to test its generality with a large and fairly complete dataset of bilateral trade statistics on forest-based commodities (United Nations, 2105), and to use the results for forecasting and policy analysis.

The next section of the paper presents the methods and data used in the study. This is followed by a description of the econometric results, and two applications of the parameters: first to forecast until 2020 the trade flows implied by the most recent macroeconomic projections in IMF (2015), and second to explore the effects of the Trans-Pacific Partnership (TPP) currently negotiated on the trade of forest products within the member countries. The last part summarizes the findings and discusses some of the limitations of the approach.

Materials and methods

Gravity models

The general form of the gravity equation used here was:

$$X_{ijt} = f(Y_{it}, Y_{jt}, W_{ij}, Z_t, u_{ijt}) \quad (1)$$

where X_{ijt} referred to exports of a particular forest product from country i to country j in year t. Y_{it} was the gross domestic product (GDP) of the exporter and Y_{jt} was the GDP of the importer. W_{ij} were time-invariant characteristics

of countries i and j that affected trade, such as distance between countries, length of common borders, common language, etc. Z_t referred to variables affecting all trade flows in a particular year t, independently of Y_{it}, Y_{jt} and W_{ij}. The idiosyncratic error, u_{ijt}, was the unexplained remaining variation over trade flows, ij, and time, t.

Rather than seeking necessarily imperfect and incomplete proxies of the time-invariant variables, W_{ij}, model (1) was formulated in differential form, thus eliminating the unobserved effects, W_{ij}, the differences between countries that remain constant over time (Wooldridge, 2002, p. 279). Differencing was also helpful to avoid spurious correlations due to the positive trends in the trade and GDP series (Verbeek, 2008, p. 327). Thus, the empirical model was:

$$\Delta \ln X_{ijt} = \alpha + \beta \Delta \ln Y_{it} + \gamma \Delta \ln Y_{jt} + \sum_{t=3}^{\theta} \delta_t Z_t + u_{ijt} i = 1, \ldots, m; \quad j = 1, \ldots, n; t = 2, \ldots, \theta \tag{2}$$

where ln was the natural logarithm of a variable, and Δ indicated differences from $t-1$ to t. With all variables expressed in logarithms, and t in years, the dependent variable was the annual rate of growth of exports from i to j, β was the elasticity of the bilateral trade with respect to the GDP of the exporting country and γ the elasticity of bilateral trade with respect to the importing country. From theory, both β and γ were expected to be positive and near unity (Anderson and Wincoop, 2003). Z_t was a dummy variable with value 1 in year t and 0 otherwise to account for time effects independent of the other variables (Baltagi *et al.*, 2003; Baier and Bergstrand, 2007). Thus, δ_t was the difference in annual growth rate of exports in year t relative to the average growth. m and n were, respectively, the number of exporting and importing countries and θ was the number of years in the dataset.

Estimation methods

Equation (2) was estimated with panel data from multiple countries and years. Each observation was the export of a particular commodity group between a country pair (ij) in a given year, t. To assess the robustness of the results, three estimation methods were used: ordinary least squares (OLS), fixed effects (FE) and random effects (RE). Each one made different assumptions regarding the form of the residuals, u_{ijt}.

OLS assumed that u_{ijt} was identically distributed, independently of the explanatory variables, with 0 mean and constant variance across trade flows, ij, and years, t.

The fixed-effects approach assumed $u_{ijt} = a_{ij} + \varepsilon_{ijt}$, where a_{ij} was a constant for each trade flow, ij. Thus, each a_{ij} measured the difference in growth rate of exports for a particular country pair due to other variables than those explicitly in the model. The residual ε_{ijt} was identically distributed, independently of the explanatory variables, with 0 mean and constant variance across trade flows, ij, and years, t. The residuals of model (2) estimated by FE were compared with those obtained by OLS with an F-test, under the null hypothesis that the country effects (a_{ij}) were nil. Rejection of the null suggested that the OLS model was incomplete, and the FE, i.e. with explicit country-pair effects, was superior.

The random-effects estimation assumed $u_{ijt} = v_{ij} + \varepsilon_{ijt}$, where v_{ij} was a random variable independent from the explanatory variables, and ε_{ijt} was defined as in the FE approach. If this was true, avoiding introduction of the constants a_{ij} increased the degrees of freedom and estimation efficiency.

The OLS, RE and FE estimations were carried out with the Stata software (Stata, 2011) with the xtreg, GLS random-effects option for the RE model, the xtreg, fixed-effects option for the FE model and the regress option for the OLS model. All three methods were all applied with robust estimation of the standard errors to account for possible heteroscedasticity or within-group correlation (Stata, 2011, p. 459). For each method, this had no effect on the coefficients and it changed their standard errors only slightly in the present context.

Data

Annual export data from each reporting country to each partner country with positive exports were obtained for the years 2005 to 2014 from the UN comtrade database (United Nations, 2015), for three commodity groups with the following harmonized system (HS) codes:

HS44: wood and articles of wood, wood charcoal,
HS47: pulp of wood, fibrous cellulosic material, waste, etc.,
HS48: paper and paperboard, articles of pulp, paper and board,

Each group contents are described further in United Nations (2015). The available data were in current US dollars. They were converted in constant US dollars of 2005 with the US implicit GDP price deflator (US Bureau of Economic Analysis, 2015).

The annual data on the GDP of each country, in constant US dollars of 2005, were obtained for the years 2005–2014 from the World Bank development indicators database (World Bank, 2015).

Figure 1 shows the aggregated world yearly exports for each commodity group during the observation period. Exports of HS44 which represented 13 per cent of the total HS44 + 47 + 48 in 2014 were only 2 per cent higher in 2014 than in 2005. World exports of HS47 did grow by 37 per cent in the same period, but they represented the smallest share (13 per cent) of total exports. Meanwhile, exports of HS48, which comprised 50 per cent of the total, were practically the same in 2015 as in 2009. For all three commodity groups, the data showed a marked contraction of world exports in 2009.

The summary statistics of the detailed data used in the econometrics are in Table 1. The number of observations ranged from 23 877 in 4942 country pairs for HS47 (pulp of wood) to 88 763 in 14 016 country pairs for HS48 (paper and paperboard). The average value of annual exports ranged from $12.1 million for HS44 (wood and articles of wood) to $16.2 million for HS48. There was wide variation around these means, and more variation between country pairs than within country pairs, underlying the advantage of the panel data approach that pools observations across country pair and over time to exploit the full variability of the data.

Application to forecasting

After obtaining the empirical models described above, they were used to forecast the yearly changes in future trade flows from 2015 to 2020,

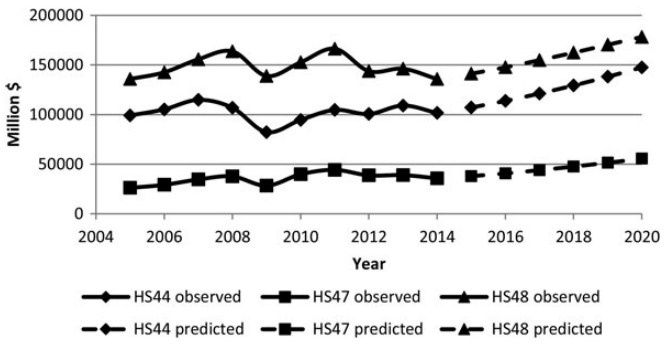

Figure 1 Observed and predicted total world exports of HS44 (wood and articles of wood, wood charcoal), HS47 (pulp of wood, fibrous cellulosic material) and HS48 (paper and paperboard, articles of pulp, paper and paperboard). Observations were from United Nations (2015). Projections were the sum of individual bilateral trade flows based on the gravity equations and the GDP projections in IMF (2015). Data are in constant $US of 2005.

Table 1 Summary statistics for export and GDP data by commodity group, in constant million $US of 2005

Commodity	Variable	Mean	Std. dev.	Observations
HS44	Exports			
	Overall	12.1	119.0	$N = 82\,980$
	Between		86.2	$n = 13\,937$
	Within		41.4	$\bar{T} = 6.0$
	GDP exporter			
	Overall	793 921	2 021 141	$N = 82\,980$
	Between		1 724 851	$n = 13\,937$
	Within		160 684	$\bar{T} = 6.0$
	GDP importer			
	Overall	623 593	1 826 183	$N = 82\,980$
	Between		1 602 325	$n = 13\,937$
	Within		124 118	$\bar{T} = 6.0$
HS47	Exports			
	Overall	14.5	97.1	$N = 23\,877$
	Between		65.3	$n = 4942$
	Within		26.9	$\bar{T} = 4.8$
	GDP exporter			
	Overall	1 393 575	2 957 020	$N = 23\,877$
	Between		2 508 196	$n = 4942$
	Within		169 424	$\bar{T} = 4.8$
	GDP importer			
	Overall	856 522	2 079 603	$N = 23\,877$
	Between		1 898 197	$n = 4942$
	Within		161 534	$\bar{T} = 4.8$
HS48	Exports			
	Overall	16.2	136.0	$N = 88\,763$
	Between		107.0	$n = 14\,016$
	Within		23.8	$\bar{T} = 6.3$
	GDP exporter			
	Overall	839 473	2 023 986	$N = 88\,763$
	Between		1 725 818	$n = 14\,016$
	Within		158 382	$\bar{T} = 6.3$
	GDP importer			
	Overall	534 609	1 712 731	$N = 88\,763$
	Between		1 572 620	$n = 14\,016$
	Within		111 816	$\bar{T} = 6.3$

HS44, wood and articles of wood, wood charcoal; HS47, pulp of wood, fibrous cellulosic material, waste, etc.; HS48, paper and paperboard, articles of pulp, paper and board; *N*, number of observations; *n*, number of country pairs.
$\bar{T}$, average number of yearly observations per country pair.

conditional on the GDP projections of the International Monetary Fund (IMF, 2015). The forecasting equation was:

$$\Delta \ln \hat{X}_{ijt} = \bar{\alpha} + \bar{\beta}\Delta \ln Y^f_{it} + \hat{\gamma}\Delta \ln Y^f_{it}, \quad i = 1, \ldots, m;\ j = 1, \ldots, n;\ t = 2015, \ldots, 2020 \tag{3}$$

where $\hat{\alpha}$,$\hat{\beta}$ and $\hat{\gamma}$ were the estimated parameters, Y^f_{it} and Y^f_{jt} were, respectively, the exogenous predictions of GDP in the exporting and importing country and $\hat{X}_{ijt}$ was the predicted export conditional on the GDPs and Δ indicated the yearly differences. With the small growth rates considered here, the differences in the logarithms of variables were close to their rates of growth. Equation (3) assumed that the only predictable export growth was induced by the changes in GDP, and any observed trend, $\hat{\alpha}$, while the time shocks, Z_t, in equation (2) were unpredictable.

Application to policy analysis

As an example of application in policy analysis, the gravity equations estimated above were used to predict the impact of the TPP on the regional trade of forest products. The agreement under current negotiation is among 12 countries: Australia, Canada, Chile, Brunei Darussalam, Japan, Malaysia, Mexico, New Zealand, Peru, Singapore, the US and Vietnam. Narayanan and Sharma (2014) project with a general equilibrium model the long-term (5 years) effect of the TPP on the GDP of the countries. Given these projections, equation (3) was used to predict the changes in trade flows induced by these changes in GDP.

Table 2 Results of estimation of gravity trade model for commodity group HS44 (wood and articles of wood, wood charcoal), with different panel methods

Variable	Method					
	OLS		FE		RE	
	Coef.	SE	Coef.	SE	Coef.	SE
$\Delta\ln(Yi)$	0.33	0.19*	0.44	0.27	0.31	0.20
$\Delta\ln(Yj)$	1.95	0.15***	1.90	0.21***	1.92	0.18***
Z_{07}	0.13	0.03***	0.10	0.03***	0.12	0.03***
Z_{08}	0.06	0.03**	0.02	0.03	0.05	0.03*
Z_{09}	−0.22	0.03***	−0.27	0.04***	−0.24	0.03***
Z_{10}	0.05	0.03*	−0.01	0.03	0.03	0.03
Z_{11}	0.09	0.03***	0.03	0.03	0.07	0.03**
Z_{12}	−0.05	0.03*	−0.12	0.03***	−0.08	0.03**
Z_{13}	0.04	0.03	−0.05	0.03*	0.01	0.03
Z_{14}	0.05	0.03*	−0.05	0.03	0.02	0.03
Constant	−0.04	0.02	0.02	0.03	−0.02	0.02
F(10 252, 52 619)				0.87		

OLS, FE, RE, ordinary least squares, fixed country effects and random country effects, respectively.
Y_i, Y_j, GDP of exporter and importer, respectively.
Z_t, fixed effect for year t.
SE, robust standard errors.
***, **,*: coefficients statistically significant at 1 per cent, 5 per cent and 10 per cent level, respectively.
F, test of significance of fixed country effects.

Table 3 Results of estimation of gravity trade model for commodity group HS47 (pulp of wood, fibrous cellulosic material), with different panel methods

Variable	Method					
	OLS		FE		RE	
	Coef.	SE	Coef.	SE	Coef.	SE
$\Delta\ln(Yi)$	1.67	0.55***	1.63	0.73**	1.87	0.56***
$\Delta\ln(Yj)$	1.10	0.36***	1.24	0.51**	1.10	0.37***
Z_{07}	0.16	0.06***	0.14	0.06**	0.15	0.06**
Z_{08}	0.15	0.06***	0.09	0.06	0.14	0.06**
Z_{09}	−0.14	0.08*	−0.17	0.09*	−0.14	0.08*
Z_{10}	0.32	0.06***	0.26	0.06***	0.30	0.06***
Z_{11}	0.02	0.06	−0.04	0.06	0.00	0.06
Z_{12}	−0.19	0.06***	−0.29	0.06***	−0.22	0.06***
Z_{13}	−0.07	0.06	−0.22	0.07***	−0.11	0.06*
Z_{14}	0.04	0.06	−0.11	0.07	−0.01	0.06
Constant	−0.07	0.05	0.00	0.06	−0.05	0.05
F(3193, 13 585)				0.89		

OLS, FE, RE, ordinary least squares, fixed country effects and random country effects, respectively.
Y_i, Y_j, GDP of exporter and importer, respectively.
Z_t, fixed effect for year t.
SE, robust standard errors.
***, **,*: coefficients statistically significant at 1 per cent, 5 per cent and 10 per cent level, respectively.
F, test of significance of fixed country effects.

Results

Econometric results

Gravity equations for HS44 (wood and articles of wood)

Table 2 shows the results of estimating model (2) with the data for commodity group HS44 and the three methods. In accord with theory, the elasticities with respect to the GDP of the exporter and importer were both positive. However, the exporter elasticity was much smaller than the importer. In fact, the exporter elasticity was marginally significant only with the OLS estimation. The importer elasticity instead was highly significant (1 per cent level) with the three methods, and close to 2.0.

The large and highly significant coefficients of Z_{07} and Z_{09} observed with all three methods indicated a higher than average (by 10–13 per cent) growth rate of trade in 2007 and a lower than average growth (by 22–27 per cent) in 2009, the later presumably due to the global economic crisis of the period. Exports were also 5–12 per cent lower than average in 2012.

The F-test suggested that the country effects used in the FE estimation could be dropped as they were not statistically significant. The OLS estimates were therefore unbiased, and given the large number of country effects which decreased substantially the number of degrees of freedom under FE, the OLS estimates were more efficient. Nevertheless, apart from the smaller standard errors under OLS, the OLS and FE results were very close. The RE approach which assumed random country effects gave coefficients and standard errors that were even closer to the OLS results.

Gravity models for HS47 (pulp of wood, fibrous cellulosic materials, waste. . .)

For commodity group HS47, the results in Table 3 showed the expected positive elasticities of trade with respect to the GDP of importers and exporters. Compared with HS44, the elasticities were more symmetric, but suggested a somewhat larger effect of the exporter GDP growth than of the importer. All the elasticities were highly significant (1 per cent level), and between 1.0 and 2.0.

Similarly to HS44, there was a 14–16 per cent higher than average trade growth of HS47 in 2007, and a drop of 14–17 per cent in 2009, but more substantial was the decrease of 19–29 per cent in 2012 depending on the method.

As for HS44, the F-test could not reject the hypothesis that the fixed country effects used in the FE approach were not significantly different from zero, suggesting that the OLS estimates were unbiased and more efficient, as indeed they had lower standard errors. Still, the OLS and FE results were quite close. The OLS results and those of RE were even closer in magnitude, and their standard errors were practically identical.

Gravity models for HS48 (paper and paperboard, articles of pulp, paper and board)

Table 4 contains the results of estimation for commodity group HS48. The elasticity of exports with respect to the GDP of importers was highly significant (1 per cent level) with all three methods, and close to 1.0. The elasticity with respect to the GDP of the exporters was

Table 4 Results of estimation of gravity trade model for commodity group HS48 (paper and paperboard), with different panel methods

Variable	Method					
	OLS		FE		RE	
	Coef.	SE	Coef.	SE	Coef.	SE
$\Delta\ln(Yi)$	0.81	0.21***	0.24	0.33	0.58	0.24**
$\Delta\ln(Yj)$	1.00	0.14***	1.04	0.19***	1.03	0.16***
Z_{07}	0.09	0.03***	0.07	0.03**	0.08	0.03***
Z_{08}	0.09	0.03***	0.04	0.03	0.07	0.03***
Z_{09}	−0.06	0.03**	−0.14	0.04***	−0.09	0.03***
Z_{10}	0.05	0.03*	0.00	0.03	0.03	0.03
Z_{11}	0.11	0.03***	0.06	0.03**	0.10	0.03***
Z_{12}	−0.12	0.03***	−0.18	0.03***	−0.14	0.03***
Z_{13}	−0.02	0.03	−0.08	0.03***	−0.04	0.03
Z_{14}	−0.03	0.03	−0.11	0.03***	−0.06	0.03**
Constant	−0.03	0.02	0.04	0.03	−0.01	0.02
F(10 785, 58 373)				0.86		

OLS, FE, RE, ordinary least squares, fixed country effects and random country effects, respectively.
Y_i, Y_j, GDP of exporter and importer, respectively.
Z_t, fixed effect for year t.
SE, robust standard errors.
***, **,*: coefficients statistically significant at 1 per cent, 5 per cent and 10 per cent level, respectively.
F, test of significance of fixed country effects.

smaller, and not statistically significant with the FE method. However, the F-test showed that the fixed country effects used in FE were not statistically significant. They could therefore be omitted as in OLS, without induced bias and at substantial efficiency gain, leading to an elasticity of the exporter GDP of 0.81 and highly significant.

The coefficients and standard errors obtained with RE were very close to the OLS results, except possibly for the elasticity with respect to the exporter GDP. But even then, given the magnitude of the standard errors, the elasticities were not statistically different, and both were significantly different from 0.

In a time pattern similar to that observed for HS44 and HS47, the growth of exports of HS48 had been 7–9 per cent above average in 2007, 6–14 per cent below average in 2009 and 12–18 per cent below average in 2012, depending on the method.

Forecasting results

In the absence of strong evidence to prefer the FE or RE estimates, the elasticities obtained by OLS were used in forecasting with equation (3). As the trend terms $\hat{\alpha}$ were not significantly different from 0, they were set to 0 in the projections. Tables 5–7 show the projected annual growth rates of trade between countries from 2015 to 2020 for the 25 main trade flows of each commodity group, conditional on the International Monetary Fund projections of GDP (IMF, 2015).

Predicted trade of commodity group HS44 (wood and articles of wood)

As shown in Table 5, the fastest predicted growth rates for HS44 (12–15 per cent) were for exports to China from Indonesia, Thailand, Canada, US and Russia. They were due to the high predicted growth of GDP in China (6–7 per cent per year), and the high elasticity of HS44 exports with respect to the importer GDP (1.95 in Table 2).

Among the slowest growing exports were those to Japan, for example, from Philippines, China and Malaysia, due to the low projected growth of GDP in Japan (<1 per cent per year). Other slow growth was expected in exports from Austria to Italy and Germany to Austria due to the low predicted growth rates of GDP in Italy and Austria (~0.5 per cent per year).

Predicted trade of commodity group HS47 (pulp of wood, fibrous cellulosic material)

The fastest growth was predicted for the trade from the US to India and China, from Chile to China and from the UK to China (Table 5). These high growth rates were due to the high predicted growth rate of GDP in China (6–7 per cent per year) and India (7–8 per cent per year), coupled with the 1.10 elasticity of exports with respect to the GDP of the exporter (Table 3).

Among the slowest growing trade flows were the exports of Finland to Italy, growing from 1.5 per cent per year in 2015 to 3.7 per cent per year in 2020. Brazil exports to the US, the Netherlands and Italy were predicted to decrease in 2015, due to the negative GDP growth predicted by the IMF for Brazil (−3.03 per cent) coupled with the 1.67 elasticity of exports with respect to the GDP of exporters (Table 3). However, the same exports from Brazil were predicted to recover and grow to 5–7 per cent by 2020. Meanwhile, Brazil exports to China stayed positive and grew rapidly from 2015 to 2020 due to the high predicted growth rate of GDP in China.

Predicted trade of commodity group HS48 (paper and paperboard)

In general, the growth rates of exports of HS48 for the 25 main trade flows (Table 7) were lower than those predicted for HS44 and HS48. This was due principally to the lower elasticity of exports with respect to the importers GDP. The fastest growth of HS48 was for exports from China to Hong Kong, and to the US, near 8 per cent per year from 2015 to 2020, due to China's high projected GDP growth rate. For the same reason, the growth of exports of China to Japan stayed near 6 per cent per year, despite the slow projected growth of Japan's GDP. The lowest growth rates were predicted for exports from Germany to Austria and Italy and of Italy to Germany, traceable to the slow projected GDP growth of Austria and Italy noted above.

At world level, aggregation of the predicted individual trade flows into total predicted world exports suggested an acceleration of the world trade of the three commodity groups compared with the stagnation observed from 2005 to 2014 (Figure 1). The fastest future growth was predicted for HS47 at nearly 8 per cent per year from 2004 to 2020, followed by HS44 at 6 per cent per year, and HS48 at 5 per cent per year.

Policy analysis results

Tables 8–10 show the results of the calculations of the impact of the TPP on the member countries, for commodity group HS44, HS47 and HS48, respectively. As shown in the second row and column of each table, Naravanan and Sharma (2014) predict

Table 5 Predicted annual per cent growth of exports of commodity HS44 (wood and articles of wood), for major trade flows, obtained with gravity equations conditional on IMF (2015) GDP projections

Exporter	Importer	Value (million $2014)	Growth rate (%)					
			2015	2016	2017	2018	2019	2020
Canada	US	8861	5.4	6.1	6.3	6.0	5.0	4.5
China	US	3545	7.3	7.6	7.4	7.2	6.4	5.9
Philippines	Japan	2954	3.1	4.0	3.0	3.4	3.9	3.5
US	China	2718	14.1	13.2	12.6	12.8	13.1	13.0
US	Canada	2481	2.9	4.2	5.6	5.4	4.9	4.6
Russian Fed.	China	2127	12.0	12.1	12.0	12.4	12.8	12.8
Canada	China	1772	13.6	12.8	12.5	12.7	13.1	13.0
China	Japan	1536	3.4	4.0	2.8	3.3	3.9	3.5
Austria	Italy	1418	1.8	3.0	2.7	2.5	2.4	2.3
Poland	Germany	1418	4.1	4.2	4.1	3.7	3.7	3.7
Austria	Germany	1300	3.2	3.6	3.4	2.9	2.9	2.8
Malaysia	Japan	1099	2.7	3.4	2.5	2.9	3.4	3.0
Thailand	China	1099	14.1	13.3	12.9	13.0	13.4	13.4
Germany	Austria	1087	2.0	3.6	3.3	2.7	2.5	2.5
Indonesia	Japan	992	2.7	3.6	2.7	3.2	3.8	3.4
Canada	Japan	981	1.5	2.5	1.7	2.1	2.5	2.1
Germany	France	945	2.8	3.4	3.7	3.8	4.0	4.0
Czech Rep.	Germany	933	4.2	3.9	3.8	3.2	3.2	3.2
Belgium	France	886	2.7	3.3	3.7	3.9	4.1	4.1
Indonesia	China	874	14.8	14.0	13.5	13.8	14.3	14.3
Brazil	US	839	4.0	5.2	6.2	6.0	5.1	4.7
US	Japan	827	2.0	2.9	1.8	2.2	2.5	2.0
Sweden	Norway	803	2.6	3.4	4.1	4.5	4.7	4.7
Sweden	UK	803	5.8	5.3	5.2	5.2	4.9	4.8
Chile	US	733	5.8	6.4	6.4	6.3	5.4	5.0

that the TPP would change the GDP of the member countries by amounts ranging from a contraction of nearly 1 per cent for Brunei to nearly 11 per cent expansion for Vietnam over a 5-year period after implementation.

Effects of the TPP on trade of HS44 (wood and articles of wood)

Given these predictions, the application of equation (3), with the OLS parameters in Table 2, gave the effects in Table 8 on trade flows of commodity group HS44. Vietnam imports from all countries increased by more than 20 per cent, due to the high predicted impact of the TPP on Vietnam's GDP coupled with the high elasticity of trade with respect to the importers' GDP (1.95), and despite the small elasticity with respect to the exporters' GDP (0.33). New Zealand's imports increased by 6–10 per cent depending on the exporting country, and Japan's imports increased by 4–7 per cent. Meanwhile, due to the predicted negative impact of the TPP on Brunei, Brunei's imports of HS44 decreased from most countries, but by <2 per cent. The only exception was Brunei's imports from Vietnam which still increased due to the predicted high impact of the TPP on Vietnam's GDP. In fact, Vietnam's exports to all countries increased by 3–10 per cent depending on the destination.

Effects of the TPP on trade of HS47 (pulp of wood, fibrous materials)

As shown in Table 9, for the wood pulp trade, the TPP largest impacts were on Vietnam's imports (11–17 per cent depending on the origin) and exports (18–20 per cent depending on destination). The other main effects were on New Zealand's exports which increased by 4.5–17 per cent depending on destination. Japan's exports also increased, by 2.5–15 per cent. The differences in the impact of the TPP on HS47 compared with HS44 stemmed from the combined effects of higher elasticity of trade with respect to the exporters GDP (1.67 *vs* 0.33), but smaller elasticity with respect to the importer GDP (1.10 *vs* 1.95).

Effects of the TPP on trade of HS48 (paper and paperboard)

The projected impact of the TPP on the trade of paper and paperboard (Table 10) was similar in sign, but smaller in magnitude, to the effect on the trade of wood pulp (HS47). This was due primarily to the elasticity of imports with respect to the exporters GDP, estimated at 1.67 for HS47, compared with 0.81 for HS48. Nevertheless, the changes for Vietnam were still substantial, as its exports increased by 8–12 per cent depending on destination, while its imports were 10–13 per cent higher than without the TPP. New

Table 6 Predicted annual per cent growth of exports of commodity group HS47 (pulp of wood, fibrous cellulosic material, waste, etc.), for major trade flows, obtained with gravity equations conditional on IMF (2015) GDP projections

From	To	Observed (million$) 2014	Predicted growth rate (%)					
			2015	2016	2017	2018	2019	2020
US	China	2370	11.8	11.7	11.3	11.2	10.7	10.2
Canada	China	1862	9.2	9.7	10.6	10.6	10.5	10.3
Canada	US	1777	4.6	5.9	7.1	6.8	6.0	5.5
Brazil	China	1185	2.4	5.2	10.4	10.7	11.1	11.2
Chile	China	838	11.3	11.1	11.4	11.9	12.5	12.8
Brazil	US	694	−2.2	1.4	6.8	6.9	6.5	6.4
Brazil	The Netherlands	652	−3.1	0.3	5.9	6.0	6.2	6.6
US	Mexico	584	6.8	7.8	8.1	8.0	7.4	6.9
Japan	China	516	8.5	8.6	7.3	7.8	8.5	8.2
Brazil	Italy	432	−4.2	−0.3	5.0	5.2	5.3	5.3
US	India	432	12.3	12.9	13.0	12.9	12.2	11.8
Finland	China	398	8.2	8.4	8.6	8.8	9.4	9.6
Sweden	Germany	398	6.3	6.7	6.2	5.5	5.2	5.0
UK	China	364	11.7	10.7	10.3	10.5	10.6	10.5
US	Japan	355	4.9	5.8	5.2	5.2	4.7	4.1
Finland	Germany	330	2.3	3.2	3.6	3.5	3.8	4.0
Canada	Indonesia	288	6.9	8.4	10.1	10.3	10.2	10.0
The Netherlands	Germany	288	4.7	4.8	4.9	4.5	4.7	4.9
US	Korea, Rep.	262	7.2	8.2	8.6	8.4	7.7	7.2
Canada	Japan	245	2.4	3.9	4.5	4.6	4.6	4.1
South Africa	China	245	9.8	9.2	10.1	10.9	11.3	11.3
US	Canada	237	5.4	6.6	7.3	7.0	6.1	5.5
Sweden	The Netherlands	229	6.6	7.0	6.7	6.1	5.9	5.9
Chile	The Netherlands	212	5.8	6.2	7.0	7.2	7.7	8.2
Finland	Italy	212	1.5	2.9	3.2	3.3	3.6	3.7

Zealand's exports also increased, by 2–13 per cent, and those from Japan by 1–12 per cent depending on destination.

Summary and conclusion

This study developed and applied empirical models of multi-lateral trade in forest products. The theory used a gravity equation whereby the trade was determined by the GDP of the exporter and importer, other characteristics of the countries and time-related changes. The model was formulated in differential form to control for time-invariant country-specific effects. Estimation was performed with panel data from the complete UN-Comtrade database from 2005 to 2014, for annual bilateral trade values of commodity groups HS44 (wood and articles of wood), HS47 (pulp of wood, fibrous cellulosic material, waste, etc.) and HS48 (paper and paperboard).

The statistical analysis was done with OLS, fixed-effects and random-effects estimation methods. All three methods gave similar results for each commodity group. For HS44, exports were inelastic (0.33 ± 0.19) with respect to the GDP of exporters and elastic (1.95 ± 0.15) with respect to the GDP of importers. For HS47, exports were elastic with respect to the exporters GDP (1.67 ± 0.55) and importers GDP (1.10 ± 0.36). Exports of HS48 were inelastic with the exporters GDP (0.81 ± 0.21) and elastic with respect to the importers (1.00 ± 0.14). For all three products, there was a marked decrease in exports in 2009 and 2012 independent of changes in GDP.

As an example of application, the derived elasticities were applied to forecast the changes in trade flows between countries from 2015 to 2020, given the GDP growth rates projected by the International Monetary Fund. Faster growth rates were predicted for the group HS47 (wood pulp) compared with HS44 and HS48. The fastest growth was predicted for trade flows to and from China. In total, the results suggested a recovery of the world forest products trade compared with the stagnation from 2005 to 2014.

Another application dealt with the impact of the TPP on the trade of forest products among the 12 participating countries. The calculations used the elasticities derived above with the projections of the long-term changes of GDP obtained by Naravanan and Sharma (2014). The largest predicted impacts were for imports and exports from Vietnam and New Zealand, especially for commodity group HS44 (wood and articles of wood).

Like most econometric projections, such forecasts must be viewed cautiously. They are subject to large potential errors. Some errors are due to the gravity equations themselves. The derived elasticities are expected values over a very large number of trade flows and years of observation. There was strong statistical evidence supporting the gravity hypothesis, but as indicated by the standard errors of the elasticities, there were substantial variations for individual trade flows and years. Other sources of error stem from the GDP projections that underlie the forecasts and the policy analyses. These projections have been developed with econometric macro-economic models that are themselves subject to large potential errors. In particular,

Table 7 Predicted annual per cent growth of exports of commodity HS48 (paper and paperboard), for major trade flows, obtained with gravity equations conditional on IMF (2015) projections

From	To	Value (million $2014)	Growth rate (%)					
			2015	2016	2017	2018	2019	2020
Canada	US	5078	3.4	4.2	4.8	4.6	4.0	3.6
US	Canada	3639	3.1	4.0	4.7	4.5	3.9	3.6
US	Mexico	2793	4.4	5.1	5.4	5.4	5.1	4.9
Germany	France	1862	2.4	2.7	2.9	2.8	2.9	2.9
China	US	1777	8.1	7.9	7.7	7.6	7.4	7.1
Germany	The Netherlands	1439	3.0	3.1	3.2	2.9	3.0	3.2
Germany	Poland	1354	4.8	4.8	4.8	4.6	4.6	4.6
Sweden	Germany	1354	3.7	4.0	3.7	3.3	3.1	3.0
Germany	UK	1270	3.7	3.5	3.4	3.3	3.2	3.1
Austria	Germany	1100	2.1	2.9	2.7	2.2	2.2	2.1
China	Hong Kong	1100	8.0	7.8	7.6	7.8	8.3	8.4
France	Germany	1100	2.4	2.8	2.8	2.7	2.8	2.8
Finland	Germany	1016	1.8	2.3	2.5	2.3	2.5	2.5
Germany	Austria	1016	2.0	2.9	2.7	2.2	2.1	2.1
Germany	Italy	1016	2.0	2.6	2.4	2.1	2.1	2.0
The Netherlands	Germany	1016	3.0	3.1	3.1	2.8	2.9	3.0
Belgium	France	931	2.2	2.6	2.8	3.0	3.1	3.1
Germany	Belgium	931	2.6	2.7	2.7	2.5	2.6	2.6
Italy	France	931	1.8	2.5	2.6	2.6	2.7	2.7
Poland	Germany	931	4.4	4.4	4.4	4.2	4.2	4.2
China	Japan	846	6.1	6.1	5.3	5.6	6.0	5.8
Mexico	US	813	4.4	5.1	5.3	5.3	4.9	4.7
Italy	Germany	779	2.2	2.6	2.4	2.2	2.1	2.1
Sweden	UK	745	4.7	4.6	4.4	4.2	4.0	3.9
Spain	France	728	3.6	3.5	3.5	3.4	3.4	3.3

Table 8 Predicted long-term impact of the TPP on GDP and trade of commodity group HS44 (wood and articles of wood), in per cent

Exporter		Importer											
		Australia	Brunei	Canada	Chile	Japan	Malaysia	Mexico	New Zealand	Peru	Singapore	US	Vietnam
	GDP	−0.3	−0.7	0.3	0.9	2.0	1.0	−0.2	3.1	−0.2	0.9	0.4	10.6
Australia	−0.3		−1.4	0.5	1.7	3.7	1.8	−0.4	6.0	−0.5	1.6	0.6	20.7
Brunei	−0.7	−0.7		0.4	1.6	3.6	1.6	−0.5	5.9	−0.6	1.5	0.5	20.5
Canada	0.3	−0.4	−1.2		1.9	3.9	2.0	−0.2	6.2	−0.3	1.8	0.8	20.9
Chile	0.9	−0.2	−1.0	0.9		4.1	2.2	0.0	6.4	−0.1	2.0	1.0	21.1
Japan	2.0	0.1	−0.7	1.3	2.4		2.5	0.3	6.7	0.2	2.4	1.4	21.4
Malaysia	1.0	−0.2	−1.0	0.9	2.1	4.1		0.0	6.4	−0.1	2.0	1.0	21.1
Mexico	−0.2	−0.6	−1.4	0.6	1.7	3.8	1.8		6.0	−0.4	1.7	0.7	20.7
New Zealand	3.1	0.5	−0.3	1.6	2.8	4.8	2.9	0.7		0.6	2.7	1.7	21.8
Peru	−0.2	−0.6	−1.4	0.6	1.7	3.7	1.8	−0.4	6.0		1.6	0.7	20.7
Singapore	0.9	−0.2	−1.0	0.9	2.1	4.1	2.2	0.0	6.4	−0.1		1.0	21.0
US	0.4	−0.4	−1.2	0.7	1.9	3.9	2.0	−0.2	6.2	−0.3	1.8		20.9
Vietnam	10.6	3.0	2.2	4.1	5.3	7.3	5.4	3.2	9.6	3.1	5.2	4.2	

GDP, predicted impact of TPP agreement on gross domestic product (Naravanan and Sharma, 2014), in per cent. Other data were derived with gravity equations.

the economic situation at the time of this writing suggests that the IMF projections of China's GDP growth may well turn out to be overly optimistic.

Despite these limitations, shared to a large extent with other approaches, the gravity equation method has the advantage of simplicity and transparency. All the data are readily available,

Table 9 Predicted long-term relative impact of the TPP on GDP and trade of commodity group HS47 (pulp of wood, fibrous cellulosic materials), in per cent

Exporter		Importer											
		Australia	Brunei	Canada	Chile	Japan	Malaysia	Mexico	New Zealand	Peru	Singapore	US	Vietnam
	GDP	−0.3	−0.7	0.3	0.9	2.0	1.0	−0.2	3.1	−0.2	0.9	0.4	10.6
Australia	−0.3		−1.2	−0.1	0.6	1.7	0.6	−0.6	3.0	−0.7	0.5	0.0	11.3
Brunei	−0.7	−1.4		−0.8	−0.1	1.0	−0.1	−1.3	2.3	−1.3	−0.2	−0.7	10.6
Canada	0.3	0.2	−0.2		1.5	2.7	1.6	0.4	4.0	0.3	1.5	0.9	12.2
Chile	0.9	1.2	0.8	1.9		3.7	2.6	1.4	5.0	1.3	2.5	1.9	13.2
Japan	2.0	3.0	2.5	3.6	4.3		4.3	3.1	6.7	3.0	4.2	3.7	15.0
Malaysia	1.0	1.3	0.9	1.9	2.6	3.7		1.4	5.0	1.4	2.6	2.0	13.3
Mexico	−0.2	−0.6	−1.0	0.1	0.7	1.9	0.8		3.2	−0.5	0.7	0.1	11.4
New Zealand	3.1	4.9	4.5	5.6	6.2	7.4	6.3	5.0		5.0	6.2	5.6	16.9
Peru	−0.2	−0.6	−1.1	0.0	0.7	1.8	0.7	−0.5	3.1		0.6	0.1	11.4
Singapore	0.9	1.2	0.7	1.8	2.5	3.6	2.5	1.3	4.9	1.2		1.9	13.2
US	0.4	0.3	−0.1	1.0	1.6	2.8	1.7	0.4	4.0	0.4	1.6		12.3
Vietnam	10.6	17.5	17.0	18.1	18.8	19.9	18.8	17.6	21.2	17.5	18.7	18.2	

GDP, predicted impact of TPP agreement on gross domestic product (Naravanan and Sharma, 2014), in per cent. Other data were derived with gravity equations.

Table 10 Predicted long-term relative impact of the TPP on GDP and trade of HS48 (paper and paperboard), in per cent

Exporter		Importer											
		Australia	Brunei	Canada	Chile	Japan	Malaysia	Mexico	New Zealand	Peru	Singapore	US	Vietnam
	GDP	−0.3	−0.7	0.3	0.9	2.0	1.0	−0.2	3.1	−0.2	0.9	0.4	10.6
Australia	−0.3		−0.9	0.1	0.7	1.7	0.7	−0.4	2.9	−0.4	0.7	0.2	10.4
Brunei	−0.7	−0.8		−0.2	0.4	1.4	0.4	−0.7	2.6	−0.7	0.3	−0.2	10.1
Canada	0.3	0.0	−0.4		1.2	2.2	1.2	0.1	3.4	0.1	1.1	0.6	10.9
Chile	0.9	0.5	0.1	1.1		2.7	1.7	0.6	3.9	0.5	1.6	1.1	11.4
Japan	2.0	1.3	0.9	1.9	2.5		2.5	1.4	4.7	1.4	2.5	2.0	12.2
Malaysia	1.0	0.5	0.1	1.1	1.7	2.7		0.6	3.9	0.6	1.7	1.1	11.4
Mexico	−0.2	−0.4	−0.8	0.2	0.8	1.8	0.8		3.0	−0.3	0.7	0.2	10.5
New Zealand	3.1	2.3	1.9	2.8	3.4	4.5	3.5	2.4		2.3	3.4	2.9	13.2
Peru	−0.2	−0.4	−0.8	0.2	0.8	1.8	0.8	−0.3	3.0		0.7	0.2	10.5
Singapore	0.9	0.4	0.0	1.0	1.6	2.7	1.7	0.6	3.8	0.5		1.1	11.4
US	0.4	0.0	−0.4	0.6	1.2	2.3	1.3	0.1	3.4	0.1	1.2		10.9
Vietnam	10.6	8.4	7.9	8.9	9.5	10.6	9.6	8.5	11.7	8.4	9.5	9.0	

GDP, predicted impact of TPP on gross domestic product (Naravanan and Sharma, 2014), in per cent. Other data were derived with gravity equations.

and the results are easily reproduced. Applied to forecasting and policy analysis, the results represent another worthwhile source of information providing an alternative view of the world trade in forest products that can be helpful for students of the forest sector and for decision makers.

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Conflict of interest statement

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