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A gravity model analysis of trade regulations on wood products exports: Evidence from Cameroon, Ghana, and the republic of Congo

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ABSTRACT

The study assesses the impact of the Forest Law Enforcement, Governance and Trade Voluntary Partnership Agreement (FLEGT VPA) and the Lacey Act Amendment (LAA) on the export quantities of wood products from Cameroon, Ghana and the Republic of Congo using the panel gravity Poisson Pseudo Maximum Likelihood (PPML) technique. The results indicate that FLEGT VPA had a negative and significant impact on industrial roundwood export quantity from all three countries. Similarly, its effects on the export of sawnwood and wood-based panels are also negative, except for Cameroon. On the other hand, the impact of LAA appears to be mixed. These results are validated by applying an alternative Driscoll-Kraay robust standard error estimation method.

1. Introduction

Global deforestation has resulted in the loss of approximately 420 million hectares of forests since 1990 (FAO Global Forest Resources Assessment, 2020). According to the FAO Global Forest Resources Assessment (2020), between 2010 and 2020, Africa had deforested 3.9 million hectares per year, leading all continents of the world. Deforestation has a significant impact on global ecological balance and societal well-being (Villanueva et al., 2023; Murillo-Sandoval et al., 2021; Astana et al., 2020; Guan and Xu, 2018; Jonsson et al., 2015). Approximately half of the tropical logs and wood products in trade is believed to originate from illegal sources, although precise figures are lacking (Lawson and MacFaul, 2010). It's estimated that illegal timber trade accounts for around 10–15% of the total value of global forest product trade (Curtis et al., 2018; OECD, 2022). Here, illegality is defined as violations of local, national, or international laws in forest-related activities.

To curb the illegal trade of wood products, the two largest importers of wood products in the world, the United States, and the European Union (EU), launched the Lacey Act Amendment (LAA) and Forest Law Enforcement, Governance and Trade Voluntary Partnership Agreement (FLEGT VAP), respectively. The goals of these regulations are to strengthen sustainable and legal forest management, improve governance, and promote the trade of legally produced timber. Enacted in 2008, the LAA prohibits the possession, transportation, and trafficking of forest products that are found to have been connected to any kind of violation of the law along its supply chain according to the local laws where that violation occurred (US Congress, 2008). FLEGT was unveiled in 2003. One key part of the FLEGT Action plan is Voluntary Partnership Agreements (VPAs) between the EU and timber-producing countries to promote trade in legal timber products and help to close the EU market to illegal products (Union, 2023). Each VPA is a bilateral trade agreement negotiated between the EU and a timber-exporting country. While parties enter a VPA voluntarily, the agreement becomes legally binding when both parties ratify it. Furthermore, the EU Timber Regulation (EUTR), which became fully operational in March 2013, serves as an extension or another crucial component of the FLEGT Action Plan. It is designed to complement the VPAs by focusing on both the supply (export) and demand (import) aspects of the timber product trade (Jonsson et al., 2015). The first VPA was signed between the EU and Ghana in 2008, nine more countries have signed VPAs with the EU since, and a number of countries are negotiating with the EU for VPAs.

The purpose of this study is to estimate the impact of FLEGT VAP and LAA on the wood products trade in three African countries, Cameron, Ghana, and the Republic of Congo. The selection of these African countries is based on their significant roles in global timber production and trade, coupled with the pressing challenges they face in combating illegal logging and promoting sustainable forest sector development. These three countries are well-known for their extensive forest resources, with timber and wood products constituting a significant

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portion of their exports. In terms of forest coverage, Cameroon has 42.1%, Ghana 35.1%, and the Republic of Congo 62% (FAO, 2022). Despite their abundant forest resources, these countries grapple with issues such as weak governance, inadequate law enforcement, and conflicts over land rights, which fuel illegal logging activities.

Lawson and MacFaul (2010) found decreased illegal logging after the millennium along with higher timber product prices. Prestemon (2015) studied U.S. import data, revealing price increases and general import quantity reductions of tropical hardwoods from countries suspected of substantial illegal timber trade. Anecdotal data indicates that temperate wood substitution is driving the EU's reduced demand for tropical wood (FLEGT IMM, 2023). Gan et al. (2016) found that environmental concerns have led to a notable decline in tropical timber usage in the European flooring industry. Rougieux and Jonsson (2021) shock model analysis suggests decreased supply, higher import prices, and lower quantities of tropical hardwood lumber post-EUTR initiation. Compliance costs imposed by EUTR may have contributed to this trend (Giurca and Jonsson, 2015; FLEGT IMM, 2023). Additional studies on global regulations include Acheampong and Maryudi (2020); Adams et al. (2020); Mbatu (2020); McDermott et al. (2020); Brusselaers and Buysse (2018); Cerutti et al. (2020); Ramcilovic-Suominen et al. (2019); Das et al. (2018); Maryudi (2016), and Maryudi et al. (2015). None of these studies look into the impacts of FLEGT VPAs and the LAA together on wood product exports from African countries.

In this paper, we use data from FAO and apply the gravity model to estimate the effects of these two regulatory interventions on market dynamics, prices, and trade patterns. Our findings may be relevant to law enforcement, governance, and international cooperation in combating the illegal trade of logs and wood products while addressing biodiversity loss, environmental degradation, and climate change. The next section presents the data and methods used in the study. Section 3 provides the results and discussion, and the final section concludes with policy implications.

2. Data and methods

2.1. Data

Our dataset comprises wood exports of industrial round wood (IR), sawnwood (SW), and wood-based panels (WBP) from Ghana, Cameroon, and the Republic of Congo between 1990 and 2021 for trend analysis and between 1997 and 2018 for econometric analysis. It is worth noting that these countries have different trading partners. The details of different trading partners are shown in Table 1. We sourced trade data from FAOSTAT (2022).

The variables we examine in our study are the quantities of wood product exports of IR, SW, and WBP by country and spanning the data period from 1997 to 2018. Some of the trading partners have missing values and for treating missing values, we employ the linear interpolation method. Our independent variables include distance, the Gross Domestic Products (GDP) of exporting and importing countries, the exchange rate, exchange rate volatility, the existence of a common language, a country's history as a colony, and FLEGT VPA and LAA as dummy variables. Table 2 includes the variables, their description, measurement, and data sources. All variables, except for the dummy variables, are transformed into natural logarithms.

Like other previous research using the gravity model, we use GDP as

Table 2
Data description and sources.

Variables	Description	Measurement	Sources
Exp	Exports of IR, SW, and WBP from three African countries	Total export quantity of industrial roundwood (IR), sawnwood (SW), and wood-based panels (WBP) (cubic meters)	FAO
Dist	Distance	Distance from three African countries to sampled nations (km)	CEPII Website
GDP_i	Gross Domestic Product of the exporting countries	Exporting country's real GDP (Constant 2015 US $ measured in billions)	WDI
GDP_j	Gross Domestic Product of the importing countries	Importing country's real GDP (Constant 2015 US$ measured in billions)	WDI
Rexch	Real Exchange Rate	Index of real exchange rate (2010 = 100)	WDI
ExchVol	Exchange rate Volatility	Exchange rate volatility	Zhang & Li, 2008
Com lg	The common language between exporting and importing countries	1 if Com lg exists, otherwise 0	CEPII Website
FLEGT	Forest Law Enforcement, Governance and Trade, Voluntary Partnership Agreement	1 if trade accords between the EU and a timber-exporting country, otherwise 0	VPA Africa-Latin America
LAA	Lacey Act Amendment	1 if trade accords between the US and a timber-exporting country, otherwise 0	Lacey ACT Amendment (2008).
Colony	A colonial historical relationship between exporting and importing countries	1 if colonial ties exist, otherwise 0	CEPII Website

Table 1
Trading partners for each country in industrial roundwood (IR), sawnwood (SW), and wood-based panels (WBP).

Cameroon			Ghana			Republic of Congo		
IR	SW	WBP	IR	SW	WBP	IR	SW	WBP
Belgium	Australia	Australia	Belgium	Australia	Australia	Belgium	Belgium	Australia
China	Belgium	Belgium	China	Belgium	Belgium	China	Canada	Belgium
France	China	China	France	China	Canada	France	China	Canada
Germany	France	France	Germany	France	China	Germany	Denmark	China
Greece	Germany	Germany	India	Germany	Denmark	India	France	France
India	Greece	Greece	Italy	Greece	France	Italy	Germany	Germany
Italy	Ireland	Italy	Japan	Ireland	Germany	Japan	Italy	Greece
Japan	Italy	Japan	Portugal	Italy	Greece	Portugal	Japan	Italy
Netherlands	Japan	Portugal	Spain	Japan	Italy	Spain	Netherlands	Mexico
Portugal	Netherlands	South Korea	Switzerland	Netherlands	Netherlands	Switzerland	Portugal	Netherlands
Turkey	Russia	Russia	Turkey	Portugal	Russia	Turkey	Russia	Portugal
UK	Spain	Spain	UK	Russia	Spain	UK	Spain	Russia
US	UK	UK		South Africa	UK		Turkey	Spain
	US	US		Spain	US		UK	US
				UK			US	
				US				

a representative measure of a country's economic size. It is commonly assumed that larger countries will have higher export volumes and the capacity to import more. The exporting and importing countries' GDP data used in our analysis are sourced from the World Development Indicators (WDI) database (World Bank, 2022). The measurement of the distance between the two countries is based on the great circle distance connecting their capital cities, and the data are sourced from the Center for International Prospective Studies and Information (CEPII) website (CEPII, 2024).

The exchange rate is represented as the amount of the trade partner country's currency per US dollar. If the value of the exchange rate increases, it indicates an appreciation of the US dollar, which is anticipated to negatively impact the three African countries' wood products exports. Anticipated fluctuations in exchange rates are likely to have an adverse impact on trade, with exchange rate uncertainty being assessed based on the moving standard deviation of the exchange rate's first differences during the preceding ten years. We calculated exchange rate volatility as:

$$\sigma.rer_{k,t} = \sqrt{\sum_{l=1}^{10} \frac{\left(\Delta lnrer_{k,t-l} - \overline{\Delta lnrer_{k,t}}\right)^2}{9}} \quad (1)$$

where $\Delta lnrer_k$ stands for the first difference of natural logarithmic form of the real exchange rate (rer) between country k and US$ in year t (i.e., $lnrer_{k,t} - lnrer_{k,t-1}$). $\overline{\Delta lnrer_{k,t}}$ is the mean value of change over the previous ten years. It has been common practice in previous studies (Aghion et al., 2009; Zhang and Li, 2009) to use the standard deviation of exchange rate changes as a proxy for exchange rate uncertainty.

The presence of a common language indicates that two countries share the same language, with a positive coefficient implying enhanced trade flows due to improved communication, trust, and business interactions, while a negative coefficient suggests limited impact. Similarly, the colonial relationship denotes whether countries share a historical colonial past, with a positive coefficient indicating increased trade flows due to lasting economic ties, and a negative coefficient suggesting potential economic effects related to historical factors. The data on common language and colony are gathered from the CEPII Website as well.

2.2. Econometric techniques

We have done several diagnostic tests, such as the cross-section dependence (CD) test and panel unit-root test. These tests assist in selecting the most suitable regression approach for analyzing the data in our study. Additionally, we employ the Poisson Pseudo maximum likelihood (PPML) technique as the primary regression and utilize the Driscoll-Kraay Robust standard error approach to verify the robustness of the PPML results.

2.2.1. Cross-section dependence (CD) test

Most traditional econometric panel data methods assume cross-sections are uncorrelated across time. In today's global economy, countries are interconnected through trade, information, capital, and globalization. This means we can estimate correlations due to these economic ties among nations in our sample. Pesaran et al. (2008) suggested using the cross-sectional dependence (CD) test to examine potential issues related to common correlation. This test is particularly useful for assessing the presence of cross-sectional independence versus cross-sectional dependence among panel units within the sample:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}\right) \quad (2)$$

where $\widehat{\rho}_{ij}$ represents the Augmented Dickey-Fuller regression-derived scales of residuals, which arise from cross-sectional pair-wise correlation; and T and N denote the time span and the number of cross-sectional entities, respectively. The null hypothesis of the CD test posits independence among sample countries, while the alternative hypothesis suggests dependence among sample countries.

2.2.2. Panel unit root test

Based on the results of the cross-sectional dependence (CD) tests, we proceed to examine the second-generation panel unit root test to determine the order of integration for our series. To investigate the unit root for panel attributes, we apply Pesaran (2007) CADF (Cross-sectional Augmented Dickey-Fuller) unit root test. The CADF test equation is as follows:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \varphi_i \Delta \bar{y}_t + \in_{it} \quad (3)$$

Here, Δ indicates the difference; y presents the examined variables; $\bar{y}_t$ and $\Delta\bar{y}_t$ signify $\frac{1}{N}\sum_{i=1}^{N} y_{it}$ and $\frac{1}{N}\sum_{i=1}^{N}\Delta y_{it}$, respectively; and $\in_{it}$ corresponds to the error term.

2.2.3. Gravity model

The gravity model, initially developed by Linneman (1966) drawing from Walrasian general equilibrium theory, has been extensively researched since Tinbergen's work in 1962, as related to its theoretical rationale and econometric formulation in international trade (Song, 2011). This widely used framework, as explained by Silva and Tenreyro (2006), posits that trade volume is directly related to the economic sizes of two countries and negatively related to the distance between them due to transportation costs and logistical challenges (Martin and Mayneris, 2015; Bergstrand et al., 2013; Bergstrand, 1985). The gravity model has two main approaches in its formal derivation: one based on the Heckscher-Ohlin model, incorporating product differentiation and consumer preferences (Anderson, 1979; Deardorff, 1998), and the other rooted in monopolistic competition within the "new" trade theory framework (Helpman, 1987). These two approaches have contributed to a comprehensive understanding of the gravity model's theoretical foundations (Redding and Weinstein, 2019).

Bergstrand (1989, 1990) merged the approaches of Dixit and Stiglitz (1977) monopolistic competition and the Heckscher-Ohlin framework, while Hummels and Levinson (1995) argued that the relationship depicted by the gravity equation is not exclusive to the monopolistic competition model, with Evenett and Keller (2002) asserting that both models are likely to explain empirical success and Haveman and Hummels (2004) suggesting that the assumption of incomplete specialization aligns better with real-world data. In addition to the traditional factors, the gravity model is extended to incorporate transportation costs, cultural similarities, language compatibility, trade agreements, political relationships, and common borders (Redding and Weinstein, 2019b; Egger and Pfaffermayr, 2003; Feenstra, 2002; Atif et al., 2017; McCallum, 1995), enabling a more comprehensive understanding of trade interactions. By estimating coefficients using statistical techniques and data on trade volumes, GDP, distance measures, and other variables, economists gain insights into the relative importance of factors and their impact on trade flows, allowing for trade concentration analysis, forecasting, policy impact assessment, and effective policy formulation (Lamica and Parajuli, 2023; Nasrullah et al. (2020); Larson et al., 2018; Zhang and Li, 2009).

The model can explain trade dynamics as it focuses on economic factors and provides a broad representation of a country's trading patterns. Anderson and van Wincoop (2003) formulate the gravity equation for trade as a multiplicative equation:

$$trade_{ijt} = A\frac{GDP_i^{\beta 1} GDP_j^{\beta 2}}{Dist_{ij}^{\alpha}} \quad (4)$$

where A indicates a normalizing constant term and $GDP_i^{\beta 1} GDP_j^{\beta 2}$ denotes

the economic scale of the trade partners. Thus, countries with larger economies are more inclined to engage in larger volumes of trade. Additionally, the presence of distance in the equation implies an inverse relationship due to increasing costs associated with proximity. Since the model is multiplicative and can pose challenges when using econometric techniques, we modified it by applying the standard log transformation, as described in Eq. (4.1).

$$ln(trade_{ijt}) = ln(A) + \beta_1 ln(GDP_i) + \beta_2 ln(GDP_j) - \alpha ln(Dist_{ij}) \quad (4.1)$$

Eq. (4.1) also lacks stochastic characteristics, which can make estimation challenging. Consequently, it is presented in an alternative form as:

$$ln(trade_{ijt}) = ln(A) + \beta_1 ln(GDP_i) + \beta_2 ln(GDP_j) - \alpha ln(Dist_{ij}) + \varepsilon_{ijt} \quad (4.2)$$

Finally, the estimated panel model can be further inferred as shown below:

$$EXP_{ij} = A \frac{GDP_i^{\beta 1} GDP_j^{\beta 2}}{Dist_{ij}^{\alpha}} \quad (5)$$

The following equation describes the impact of FLEGT VPA, and LAA, and other development variables on the export quantities of wood products from Cameroon, Ghana, and the Republic of Congo.

$$ln(EXP_{ij,t}) = ln(A) + \beta_1 ln(GDP_{it}) + \beta_2 ln(GDP_{jt}) + \beta_{it} x_{it} - \alpha ln(Dist_{ij}) + \varepsilon_{ijt} \quad (5.1)$$

Here, GDP_{it} indicates the real GDP of the exporting countries (Ghana, Cameroon, and the Republic of Congo, respectively), GDP_{jt} represents the real GDP of the importing countries, x_{it} denotes the column vector of incorporating variables, including real exchange rate, exchange rate volatility, common language, colony, FLEGT VAP and LAA. $Dist_{ij}$ indicates a time-invariant geographical distance between the exporter and importer countries and ε_{it} designates the unobserved factors.

Considerable estimation challenges are associated with the gravity model, including when fixed effects are included, which makes the gravity model non-robust to specification error (Pfaffermayr, 2019; Anderson and van Wincoop, 2003). Furthermore, the potential existence of heteroscedasticity and autocorrelation is evaluated through diagnostic testing using pooled OLS. To address these issues, this study employs the technique proposed by Santos Silva and Tenreyro's (2010) Poisson Pseudo maximum likelihood (PPML) estimation. With this approach, all potential problematic independent variables are eliminated, even those that do not produce maximum likelihood values (Santos Silva and Tenreyro, 2010). The PPML model provided with modification made by Santos Silva and Tenreyro (2015) is:

$$Pr(y_i = j|x_i) = \frac{exp(-\lambda)\lambda^j}{j!} \quad (6)$$

where $j = 0, 1, 2, 3, 4, \ldots$ log-likelihood commonly specified as $\lambda = exp(x_i^l \beta) = exp(\beta_0 + \beta_1 x_{1i} + \ldots)$. The estimator vectors can be measured using this formulation by increasing the log-likelihood function as follows:

$$lnL(\beta) = \sum_{i-1}^{n} \left[-exp(x_i^l \beta) + (x_i^l \beta) y_t - ln(y_i^!) \right] \quad (7)$$

The Poisson regression technique can be used to estimate the relationships between regressors and dependent variables in both counting and multiplicative models, including the gravity model (Santos Silva and Tenreyro, 2006), while proper inference on parameter significance requires specification of a heteroscedastically distributed error term.

2.2.4. Driscoll Kraay's standard errors technique

To test the robustness of the study results, we utilize the Driscoll Kraay standard errors technique. This technique is effective at generating robust results in circumstances where there is cross-sectional dependency and when panels are divergent. It controls for white-noise error terms in multiple panels. This problem is often seen when using macroeconomic variables that cover a long of period time (Torres-Reyna, 2007). Initially, the potential problems of heteroscedasticity, cross-sectional dependence, and serial correlation concerns are explored by applying the Driscoll Kraay standard errors. When the regressors' errors are incorporated into the model, the subsequent feature of this technique considers their average values. After that, it employs a weighted Heteroskedasticity and Autocorrelation Consistent (HAC) estimator using these data to produce cross-sectional trustworthy standard errors. The fixed effects estimator is conducted in two phases. Each variable $\tau_{it} \in \{y_{it}, x_{it}\}$ in the first stage of the model is transformed as illustrated below:

$$\widetilde{\tau}_{it} = \tau_{it} - \overline{\tau}_i + \ddot{\tau} \quad (8)$$

Here, $\overline{\tau}_i = T_i^{-1} \sum_{t=ti1}^{T_i} \tau_{it}$ and $\ddot{\tau} = (\sum T_i)^{-1} \sum_i \sum_{it} \tau_{it}$. The second stage of the within-estimator concerned with the method involves using Ordinary Least Squares (OLS) to estimate the model (i.e., $\widetilde{y}_{it} = \widetilde{x}_{it}\phi + \widetilde{\varepsilon}_{it}$). It calculates the transformed regression model in Eq. 8 within the context of the pooled OLS evaluation.

3. Results and discussion

3.1. Trend analysis

We present the wood export trend of these three African countries below.

Fig. 1 illustrates that the leading forest product exports for Cameroon are IR and SW, with their export volumes fluctuating over the years. In particular, the export of IR experienced the largest fluctuation. On the other hand, SW and WBP had a slightly different pattern: the export of SW demonstrates a consistent upward trend, while the export of WBP remains relatively stable in the study period.

The export of IR from Ghana is characterized by pronounced oscillations over time (Fig. 2). A parallel narrative unfolds with the export of WBP while the export of SW is marked by a gradual increase before 2008 and a decline afterward.

When juxtaposed with the exports of SW and WBP, the Republic of Congo exhibits a notably higher export volume for IR (Fig. 3). This pattern is typified by a cyclic ascent in one year, succeeded by a subsequent descent in the following year. In contrast, the export of SW demonstrates a steady and progressive augmentation, whereas the export of WBP experiences a marginal decline over the years.

3.2. Econometrics analysis

3.2.1. Descriptive statistics

The descriptive statistics presented in Tables 3, 4 and 5 provide insights into the export trends and economic indicators of three countries: Cameroon, Ghana, and the Republic of Congo, focusing on industrial roundwood (IR), sawnwood (SW), and wood-based panel (WBP). For each variable, the tables present the number of observations (Obs.), mean, standard deviation (Std. Dev.), minimum (Min), and maximum (Max) values. For instance, examining Cameroon's data reveals that the mean IR export (EXP) is approximately 8.15 with a standard deviation of 2.48, while the mean real GDP of the exporting country (GDP_i) is around 3.13. Similarly, in Ghana, the mean IR export is slightly lower, at 5.89, and the mean real GDP_i matches Cameroon's, at 3.41. Contrastingly, the Republic of Congo shows higher IR exports, with a mean of 8.44 but a lower GDP_i, at 2.14, compared to the other two countries.

The correlation results presented in Appendix (A1-A9) offer insights into the relationships between the variables we use in the study.

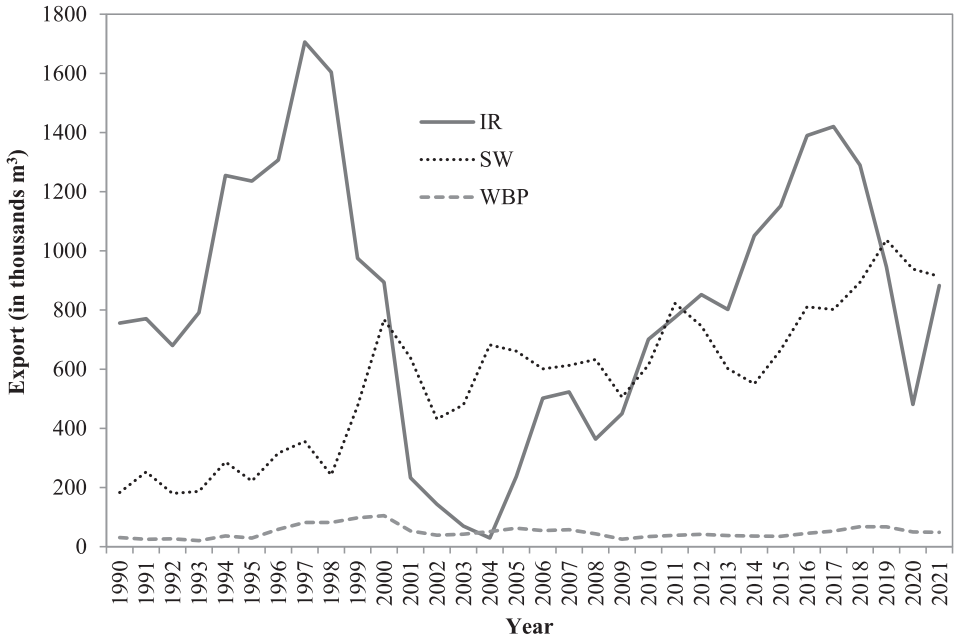

Fig. 1. Cameroon's industrial roundwood (IR), sawnwood (SW), and wood-based panels (WBP) export quantity. Data source: FAOSTAT, 2022

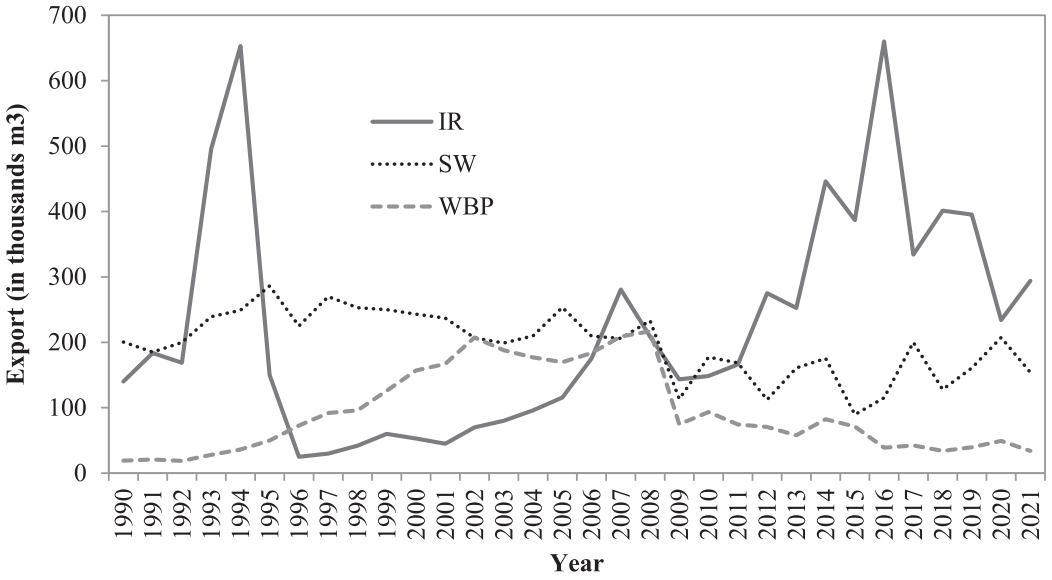

Fig. 2. Ghana's industrial roundwood (IR), sawnwood (SW), and wood-based panels (WBP) export quantity. Data source: FAOSTAT, 2022

3.2.2. Cross-sectional dependence and panel unit root tests

To ensure the validity of statistical inference, account for interdependencies among entities, improve estimation efficiency, and select appropriate econometric models, we have conducted cross-sectional dependence and panel unit root tests (Pesaran, 2007), and the results are presented in Tables 6, 7, and 8.

We examine the presence of common shock effects across countries by implementing cross-sectional dependence tests. The results of the cross-sectional dependence test (CD test) indicate that the null hypothesis of cross-section independence should be dismissed for all (dependent) variables in the model with 1% and 5% significance. In an interconnected globalized world, it is not surprising that the exports of a country are interlinked with that of others, either directly or indirectly (Salinas et al., 2023; Wang et al., 2020).

Similarly, to examine the stationarity of variables while considering cross-sectional dependence, we employ the second-generation panel unit root test introduced by Pesaran (2007), assesses the order of integration of the variables. Therefore, we conducted the CADF technique to examine the stationarity extent of given variables; findings are presented in Tables 6, 7, and 8. The results show that exports, GDP_i, the real exchange rate, and the volatility of the exchange rate are stationary in levels [i.e., I (0)], while distance and GDP_j are stationary only in their first differences [i.e., I (1)].

3.2.3. Poisson Pseudo maximum likelihood (PPML) results

The results of the PPML model estimates, shown in Table 9, offer several insights into the exports of IR, SW, and WBP for these countries. Notably, the negative and statistically significant coefficients for distance—except for Ghana and the Republic of Congo's IR—suggest that these nations' wood products exports are higher when trading with countries in closer geographic proximity. Similarly, the impact of importing countries' real GDP on IR, SW, and WBP exports is positive, as

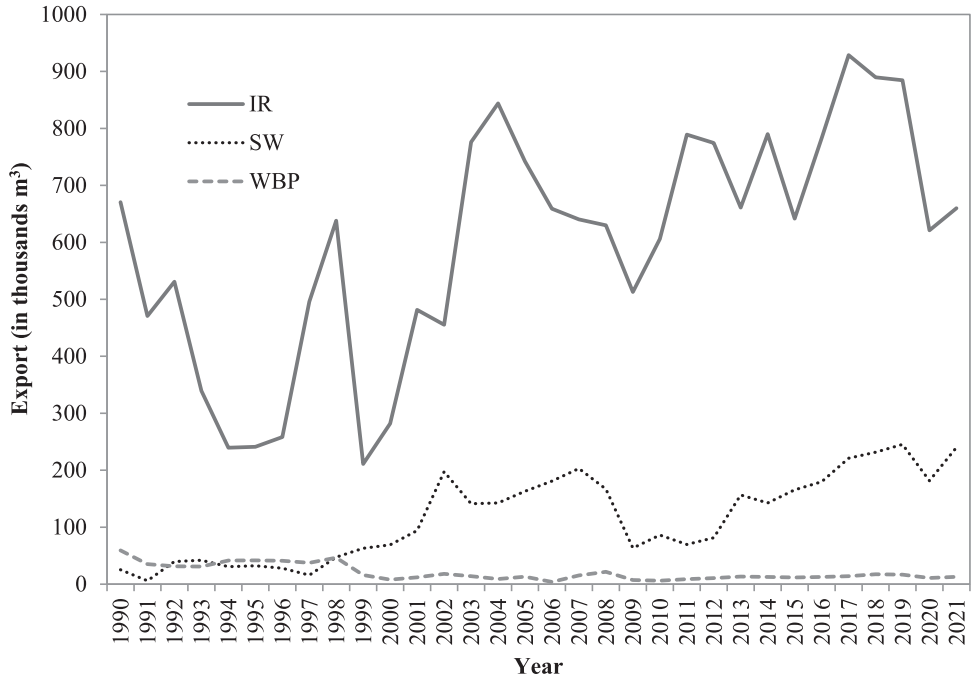

Fig. 3. Republic of Congo's industrial roundwood (IR), sawnwood (SW), and wood-based panels (WBP). Data source: FAOSTAT, 2022

Table 3
Descriptive analysis of Cameroon's industrial roundwood (IR), sawnwood (SW), and wood-based panels (WBP).

	IR					SW					WBP				
Variables	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max
EXP	286	8.15	2.48	0.69	13.30	308	8.81	2.57	0.69	12.70	308	5.85	1.92	0.69	10.67
Dist	286	8.71	0.37	8.29	9.48	308	8.77	0.41	8.29	9.59	308	8.81	0.45	8.29	9.59
GDPi	286	3.13	0.25	2.72	3.55	308	3.13	0.25	2.72	3.55	308	3.13	0.25	2.72	3.55
GDPj	286	7.26	1.27	5.14	9.85	308	7.28	1.20	4.80	9.85	308	7.31	1.19	5.14	9.85
Rexch	286	4.60	0.11	4.15	4.87	308	4.58	0.14	3.83	4.87	308	4.59	0.15	3.83	4.99
ExchVol	286	0.01	0.02	0.00	0.07	308	0.02	0.02	0.00	0.12	308	0.01	0.02	0.00	0.17
Com lg	286	0.38	0.49	0	1	308	0.43	0.50	0	1	308	0.36	0.48	0	1
FLEGT	286	0.33	0.47	0	1	308	0.33	0.47	0	1	308	0.33	0.47	0	1
LAA	286	0.04	0.19	0	1	308	0.03	0.18	0	1	308	0.03	0.18	0	1
Colony	286	0.08	0.27	0	1	308	0.07	0.26	0	1	308	0.07	0.26	0	1

Table 4
Descriptive analysis of Ghana's industrial roundwood (IR), sawnwood (SW), and wood-based panels (WBP).

	IR					SW					WBP				
Variables	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max
Exp	176	5.89	2.56	0.69	12.74	352	7.42	2.09	1.39	11.12	308	6.94	1.95	1.61	11.19
Dist	176	8.77	0.31	8.48	9.38	352	8.71	0.43	8.24	9.66	308	8.73	0.39	8.27	9.66
GDPi	176	3.41	0.37	2.87	4.01	352	3.41	0.37	2.87	4.01	308	3.41	0.37	2.87	4.01
GDPj	176	7.60	1.26	4.80	9.85	352	7.05	1.28	4.80	9.85	308	7.22	1.13	5.20	9.85
Rexch	176	4.63	0.11	4.41	4.87	352	4.58	0.13	3.83	4.87	308	4.58	0.13	3.83	4.87
ExchVol	176	0.01	0.01	0.00	0.05	352	0.01	0.02	0.00	0.12	308	0.01	0.02	0.00	0.12
Com lg	176	0.50	0.50	0	1	352	0.31	0.46	0	1	308	0.29	0.45	0	1
FLEGT	176	0.43	0.50	0	1	352	0.43	0.50	0	1	308	0.43	0.50	0	1
LAA	176	0.06	0.24	0	1	352	0.03	0.17	0	1	308	0.03	0.18	0	1
Colony	176	0.13	0.33	0	1	352	0.06	0.24	0	1	308	0.07	0.26	0	1

observed in a previous study by Huang et al. (2019). The positive and statistically significant coefficients for real exchange rates are the result of several factors, including trade competitiveness, trade balance dynamics, supply-side effects, demand elasticity, time lags, global economic conditions, and government policies. The exchange rate finding means that a depreciation of the domestic currency relative to foreign currencies enhances competitiveness in international markets, leading to higher trade volumes. Since all its costs are paid in local currencies, it makes sense that the exports to other countries increase. Exchange rate volatility, attributed to risk-taking tendencies, increased competitiveness, and price advantages, demonstrates a mixed effect on wood products exports. This makes wood product exports more appealing and lucrative for exporters (Zhang and Li, 2008. The presence of a common language among trading partners has a positive impact on exports for Ghana and the Republic of Congo. Moreover, the historical colonial relationship has a positive and significant influence on exports, except for Ghana.

Table 5
Descriptive analysis of the Republic of Congo's industrial roundwood (IR), sawnwood (SW), and wood-based panels (WBP).

	IR					SW					WBP				
Variables	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max
Exp	252	8.44	2.26	1.79	13.53	330	6.76	2.01	1.79	11.68	308	5.14	1.91	0.69	9.70
Dist	252	8.80	0.29	8.54	9.50	330	8.87	0.30	8.54	9.50	308	8.92	0.35	8.47	9.53
GDPi	252	2.14	0.24	1.78	2.51	330	2.14	0.24	1.78	2.51	308	2.14	0.24	1.78	2.51
GDPj	252	7.19	1.00	5.14	9.44	330	7.25	1.16	5.14	9.85	308	7.13	1.15	5.14	9.85
Rexch	252	4.60	0.11	4.15	4.87	330	4.58	0.14	3.83	4.87	308	4.57	0.13	3.83	4.87
ExchVol	252	0.01	0.01	0.00	0.07	330	0.01	0.02	0.00	0.12	308	0.01	0.01	0.00	0.12
Com lg	252	0.17	0.37	0	1	330	0.20	0.40	0	1	308	0.21	0.41	0	1
FLEGT	252	0.24	0.43	0	1	330	0.24	0.43	0	1	308	0.24	0.43	0	1
LAA	252	0.00	0.00	0	0	330	0.03	0.18	0	1	308	0.03	0.18	0	1
Colony	252	0.08	0.28	0	1	330	0.07	0.25	0	1	308	0.07	0.26	0	1

Table 6
Results of cross-sectional dependence (CD) tests and panel unit root tests for Cameroon.

Variables	IR			SW			WBP		
	CD test	Panel unit root test		CD test	Panel unit root test		CD test	Panel unit root test	
		CADF I (0)	CADF I (1)		CADF I (0)	CADF I (1)		CADF I (0)	CADF I (1)
Exp	11.31***	−4.93**	−16.96***	5.66***	−4.22**	−15.66***	1.77*	−5.11***	−17.04***
GDP_i		−6.71***	−12.43***		−7.61***	−12.93***		−6.99***	−12.91***
GDP_j	30.08***	−1.79	11.51***	34.46***	−2.02	−12.01***	33.60***	−2.41	−12.01***
Rexch	3.85***	−4.91**	−11.81***	7.18***	−5.72***	−11.39***	4.24***	−6.12***	−10.85***
ExchVol	7.79***	−9.92***	−20.54***	8.58***	−10.36***	−21.46***	7.08***	−8.94***	−20.95***

Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

Table 7
Results of cross-sectional dependence (CD) tests and panel unit root tests for Ghana.

Variables	IR			SW			WBP		
	CD test	Panel unit root test		CD test	Panel unit root test		CD test	Panel unit root test	
		CADF I (0)	CADF I (1)		CADF I (0)	CADF I (1)		CADF I (0)	CADF I (1)
Exp	−0.98	−4.00**	−13.26***	23.60***	−5.62***	−17.06***	16.75***	5.91***	−14.41***
GDP_i		−4.48**	−9.30***		−6.58***	−13.36***		−6.13***	−12.47***
GDP_j	23.37***	−1.29	−9.34***	39.70***	−1.99	−12.84***	34.88***	−2.75	−12.06***
Rexch	−0.88	−4.48**	−8.64***	9.51***	−6.17***	−12.38***	9.83***	−5.82***	−11.88***
ExchVol	7.28***	−8.68***	−17.04***	10.04***	−10.98***	−22.37***	9.96***	−10.71***	−21.06***

Note: *p < 0.1; **p < 0.05; ***$p < 0.0$.

Table 8
Results of cross-sectional dependence (CD) tests and panel unit root tests for the Republic of Congo.

Variables	Industrial Roundwood			Sawnwood			Wood-based Panels		
	CD test	Panel unit root test		CD test	Panel unit root test		CD test	Panel unit root test	
		CADF I (0)	CADF I (1)		CADF I (0)	CADF I (1)		CADF I (0)	CADF I (1)
Exp	0.25	−5.36***	−17.14***	6.43***	−5.77***	−15.25***	4.59***	−5.99***	−15.13***
GDP_i		−5.11***	−8.19***		−5.75***	−9.19***		−5.54***	−8.86***
GDP_j	30.87***	−2.78	−11.08***	40.69***	−2.29	−12.43***	33.81***	−1.96	−12.06***
Rexch	2.30**	−5.04***	−11.09***	9.08***	−5.41***	−12.23***	10.55***	−6.03***	−12.21***
ExchVol	6.52***	−8.91***	−19.40***	7.35***	−10.48***	−21.25***	10.88***	−10.68***	−21.39***

Note: *p < 0.1; **p < 0.05; ***p < 0.0.

As stated, our main interests are to assess the effects of FLEGT VPA[1] and the LAA on IR, SW, and WBP exports of these countries. Cameroon joined the FLEGT VPA in 2011, Ghana in 2009, and the Republic of Congo in 2013, with the LAA being amended in 2008. Our PPML analysis reveals that FLEGT VPA has negative and statistically significant coefficients for Ghana's IR, SW, and WBP exports. Specifically, Ghana's entry into the FLEGT VPA led to a decrease in the export quantity of around 14%, 19%, and 6% in IR, SW, and WBP, respectively (Table 9). Similarly, albeit to a lesser extent, the Republic of Congo's signature on the FLEGT VPA led to a decrease of its IR, SW, and WBP exports by around 7%, 6%, and 19%, respectively. In contrast, Cameroon's IR export dropped by around 16%.

In contrast to the negative effects of FLEGT VPA, LAA has yielded different outcomes for the export quantities of these countries. Notably, Cameroon's IR, Ghana's IR and WBP exports show negative and statistically significant coefficients, leading to a respective decrease of 58%, 61%, and 7% in export qualities. Conversely, Cameroon's SW, the Republic of Congo's SW and WBP exports exhibit positive coefficients of

[1] The study also looked at the EUTR as an additional variable and found it to be not consistently statistically significant.

Table 9
PPML results of Cameroon's, Ghana's, and the Republic of Congo's industrial roundwood (IR), sawnwood (SW), and wood-based panels (WBP) exports.

Variables	Cameroon			Ghana			Republic of Congo		
	IR	SW	WBP	IR	SW	WBP	IR	SW	WBP
Dist	−0.070*	−0.415***	−0.398***	0.651***	−0.260***	−0.324***	0.047	−0.447***	−0.158**
	(0.040)	(0.051)	(0.056)	(0.124)	(0.041)	(0.061)	(0.069)	(0.073)	(0.065)
GDPi	−0.501***	−0.095	−0.214**	0.128	−0.163**	−0.315***	−0.104	−0.018	−0.416***
	(0.103)	(0.091)	(0.103)	(0.151)	(0.071)	(0.072)	(0.090)	(0.078)	(0.114)
GDPj	0.112**	0.051***	0.100***	0.075**	0.103***	0.074***	0.073***	0.077***	0.021
	(0.050)	(0.017)	(0.017)	(0.030)	(0.012)	(0.014)	(0.026)	(0.020)	(0.027)
Rexch	0.473**	0.804***	−0.161	0.861***	0.415***	0.254*	−0.153	0.430***	0.381**
	(0.174)	(0.170)	(0.111)	(0.276)	(0.129)	(0.134)	(0.182)	(0.142)	(0.182)
ExchVol	0.021*	−0.019*	−0.033***	0.053**	0.006	−0.011	−0.007	0.001	−0.021
	(0.012)	(0.010)	(0.011)	(0.025)	(0.010)	(0.010)	(0.055)	(0.012)	(0.017)
FLEGT	−0.167***	0.012	0.034	−0.148*	−0.199***	−0.064*	−0.076*	−0.069*	−0.190***
	(0.057)	(0.049)	(0.053)	(0.081)	(0.057)	(0.037)	(0.045)	(0.042)	(0.060)
LAA	−0.584***	0.123**	0.074	−0.610***	0.006	−0.074*	NA	0.272***	0.441***
	(0.140)	(0.058)	(0.063)	(0.134)	(0.051)	(0.043)		(0.062)	(0.089)
Com lg	−0.197***	−0.002	−0.069*	0.237***	0.109***	0.267***	−0.009	0.129***	0.075
	(0.039)	(0.037)	(0.039)	(0.067)	(0.031)	(0.052)	(0.057)	(0.044)	(0.053)
Colony	0.275**	0.086**	0.031	−0.003	−0.195***	−0.392***	0.191***	0.071	0.338***
	(0.042)	(0.041)	(0.062)	(0.084)	(0.049)	(0.064)	(0.065)	(0.055)	(0.073)
constant	2.125**	1.930*	5.779***	−7.664***	2.273***	4.054***	2.075**	3.327***	2.120**
	(1.081)	(1.055)	(0.767)	(1.592)	(0.825)	(0.848)	(0.943)	(0.951)	(1.052)
R-squared	0.29	0.43	0.318	0.456	0.503	0.458	0.462	0.275	0.223
Obs	286	308	308	176	352	308	252	330	308

Note: *p < 0.1; **p < 0.05; ***p < 0.01. Values in parentheses below coefficients are standard errors.

12%, 27%, and 44% respectively, implying a rise in export quantities. Owing to limited data on the Republic of Congo's IR exports to the U.S., the impact of LAA on its exports could not be calculated.

To assess the robustness of the PPML results, the study employs the Driscoll-Kraay standard errors technique. This method is chosen for its capacity to manage disturbance terms across different panels associated with cross-sectional (spatial) dependency. It serves as an appropriate means of verifying robustness, particularly when *i* and *j* represent distinct panels. Like the PPML results, our robustness test affirms the significantly negative impact of IR exports from all three African countries (Table 10). Furthermore, the robustness test result validates the PPML results concerning SW and WBP exports. The same applies to the impact of LAA on IR, SW, and WBP export quantities.

In line with our findings, Apeti and N'Doua (2023) demonstrate that the implementation of timber regulations leads to a reduction in timber and timber product trade. Likewise, Molua (2023) observes that in the long-run, domestic consumption levels, effective forest regulations and increased illegal exports are negatively correlated with the export of sawn wood. While our study yielded varied effects of Lacey Act Amendment on export revenues of various timber products in African nations, Prestemon (2015) highlights the significant impacts of the 2008 Lacey Act Amendment, indicating a decrease in import quantities and an increase in import prices of tropical hardwood lumber and plywood into the U.S. Acheampong and Maryudi (2020) find that timber producers in Ghana encountered challenges in timber legality verification, leading them to adopt practices aimed at bypassing EU market legality requirements and domestic laws. Additionally, Cerutti et al., (2020) notes that progress toward various VPA-related targets suggests that the

Table 10
Robustness check results with Driscoll-Kraay standard errors for industrial roundwood (IR), sawnwood (SW), and wood-based panels (WBP) exports.

Variables	Cameroon			Ghana			Republic of Congo		
	IR	SW	WBP	IR	SW	WBP	IR	SW	WBP
Dist	−0.549*	−3.341***	−2.139***	3.904***	−2.034***	−2.368***	0.482	−2.872***	−0.743**
	(0.317)	(0.292)	(0.289)	(0.962)	(0.180)	(0.517)	(0.614)	(0.446)	(0.211)
GDPi	−4.195**	−0.870	−1.243**	0.831	−1.218	−2.224***	−0.846***	−0.177	−2.105**
	(1.325)	(1.120)	(0.472)	(0.680)	(0.947)	(0.448)	(0.262)	(0.497)	(0.945)
GDPj	0.090*	0.493***	0.552***	−0.452**	0.853***	0.571***	0.582***	0.518***	0.111
	(0.053)	(0.172)	(0.108)	(0.201)	(0.102)	(0.110)	(0.183)	(0.175)	(0.183)
Rexch	3.892*	5.778***	−0.851**	6.278**	3.112***	2.067**	−1.237	2.613**	1.882***
	(2.208)	(0.853)	(0.337)	(2.525)	(0.753)	(0.932)	(2.845)	(1.040)	(0.614)
ExchVol	0.175**	−0.202*	−0.203**	0.321**	0.041	−0.070	−0.058	0.006	−0.110*
	(0.081)	(0.119)	(0.083)	(0.149)	(0.078)	(0.089)	(0.116)	(0.094)	(0.059)
FLEGT	−1.373**	0.045	0.197	−0.326*	−1.429*	−0.399*	−0.126*	−0.488*	−0.954**
	(0.681)	(0.505)	(0.244)	(0.571)	(0.756)	(0.241)	(0.710)	(0.251)	(0.377)
LAA	−2.951***	0.710*	0.377	−3.378***	−0.406	−0.909***	NA	2.069***	2.406***
	(0.784)	(0.430)	(0.334)	(0.903)	(0.365)	(0.300		(0.504)	(0.600)
Com lg	−1.578***	0.120	−0.406**	1.374***	1.023***	2.060***	−0.083	0.821**	0.362
	(0.506)	(0.179)	(0.213)	(0.360)	(0.191)	(0.391)	(0.354)	(0.299)	(0.239)
Colony	2.314***	0.750***	0.206	−0.357	−1.714***	−3.042***	1.799***	0.771*	2.182***
	(0.489)	(0.185)	(0.385)	(0.557)	(0.284)	(0.500)	(0.377)	(0.448)	(0.362)
constant	8.468*	9.607**	27.507***	−55.826***	9.645**	21.084***	7.112**	16.517**	7.337**
	(5.055)	(5.073)	(3.592)	(18.414)	(4.137)	(6.871)	(3.687)	(7.419)	(3.224)
R-squared	0.274	0.460	0.2824	0.4149	0.524	0.476	0.245	0.284	0.226
F-test	76.79***	465.78***	76.79***	13.74***	167.460***	89.590***	115.770***	367.010***	67.070***
Obs	286	294							

Note: *p < 0.1; **p < 0.05; ***p < 0.01. Values in parentheses below coefficients are standard errors.

contribution of VPAs is generally positive and rarely negative in reducing export quantities. While FLEGT VPA has demonstrated success in numerous cases, addressing the challenges that have arisen in African countries remains pivotal.

The effectiveness of the FLEGT VPA and the LAA in these African countries hinges on their institutional capacity, which may be hindered by weak governance structures, limited resources, and inadequate enforcement mechanisms, posing challenges to the full implementation and enforcement of VPA and LAA requirements (Adams et al., 2021a; Sara and William, 2021; Astana et al., 2020). Additionally, complexities in establishing necessary legal frameworks aligned with VPA and LAA standards, compounded by stakeholder engagement issues arising from limited participation and conflicting interests, can lead to delays. The efforts to combat corruption and illicit practices associated with illegal logging, a key focus of FLEGT VPAs (Rougieux and Jonsson, 2021), may be undermined by deeply entrenched corruption networks. The degree of success also relies on market demand for legal and sustainable timber, which, if insufficient or due to lack of consumer awareness, could attenuate VPA and LAA impacts (Khanal, 2024; Appau and Derkyi, 2022; Mbatu, 2020; Brusselaers and Buysse, 2018). Furthermore, effective monitoring and evaluation of VPA and LAA implementation, particularly in tracking timber supply chains and verifying timber legality, could be challenging for these (and other) African countries.

4. Conclusion and Policy Implications

This study examines the impact of FLEGT VPAs and the LAA on the exports of wood products from three African countries. The trend analysis reflects the rapid fluctuations in the export of IR in comparison to SW and WBP in all these countries. Our econometric analysis shows that the effect of a FLEGT VPA on the export quantities of IR in all three countries is negative and significant. Although the export quantities from SW and WBP are also negatively impacted by the FLEGT VPA in the case of Cameroon and Ghana, the effects on the Republic of Congo's SW and WBP export quantities were positive. However, the LAA has produced mixed results on export quantities for these products. On the one hand, LAA leads to a significant decline in the export of SW from Cameroon and IR from Ghana. On the other hand, it has a positive impact on the exports of Cameroon's IR and WBP as well as Ghana's and the Republic of Congo's SW and WBP.

We also look at the impact of EUTR and find it to be not consistently statistically significant, with some isolated significances (i.e., a positive effect on Cameroon's exports of IR, a weak negative effect on Congo's exports of IR, a positive effect on Congo's SW and WBP exports). Perhaps EUTR interacts with VPA and serves as an enforcer of VPA. Definitively disentangling the separate VPA and EUTR effects on wood product exports remains a task left to future research.

It is important to note that while FLEGT VPAs and the LAA may face challenges in African countries, they have also shown positive outcomes in terms of improved forest governance, strengthened law enforcement, and increased transparency in the timber trade (Adams et al., 2021b; Adams et al., 2020; Hansen et al., 2018). Future research can be done by investigating the EUTR's impact as a trade measure using an updated dataset covering all countries that are affected by it and that have signed on FLEGT VPA. Furthermore, there remains a possibility that the roundwood exports from these countries may be redirected to regions outside the EU/USA, due to less stringent export regulations in those alternative regions. This exploration could serve as a valuable avenue for future research.

Author statement

I, Ghanashyam Khanal, the first author and corresponding author of the manuscript (FORPOL-D-23-00642) confirm that the manuscript is original and is not currently under consideration for publication elsewhere. Further, all named authors meet the criteria for authorship and the order of authors listed has been approved by all authors.

I, Ghanashyam Khanal, the first author and corresponding author, hereby approve the author statement on behalf of all the authors.

The authors declare no conflict of interest.

CRediT authorship contribution statement

Ghanashyam Khanal: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Daowei Zhang:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Jeffrey P. Prestemon:** Writing – review & editing.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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Appendix A. Appendix

Table A1
Correlation results of Cameroon's industrial roundwood.

	EXP	Dist	GDPi	GDPj	Rexch	ExchVol	Com lg	FLEGT	LAA	Colony
EXP	1									
Dist	−0.12	1								
GDPi	−0.25	−0.002	1							
GDPj	0.10	0.690	0.12	1						
Rexch	0.04	0.120	0.01	0.35	1					
ExchVol	0.07	0.270	−0.05	0.15	−0.15	1				
Com lg	−0.21	0.100	0.00	0.26	0.34	−0.04	1			
FLEGT	−0.11	0.000	0.80	0.09	−0.04	0.00	0.03	1		
LAA	−0.34	0.232	0.17	0.38	0.06	−0.03	0.25	0.15	1	
Colony	0.16	−0.134	0.00	0.10	0.01	−0.08	0.37	0.00	−0.06	1

Table A2
Correlation results of Cameroon's sawnwood.

	EXP	Dist	GDPi	GDPj	Rexch	ExchVol	Com lg	FLEGT	LAA	Colony
EXP	1									
Dist	−0.48	1								
GDPi	−0.02	0.00	1							
GDPj	0.07	0.47	0.12	1						
Rexch	0.46	−0.11	0.05	0.31	1					
ExchVol	−0.24	0.24	−0.02	0.14	−0.16	1				
Com lg	0.03	0.16	0.00	−0.02	0.19	−0.11	1			
FLEGT	−0.04	0.00	0.80	0.08	−0.01	0.03	−0.01	1		
LAA	0.06	0.17	0.17	0.39	0.07	−0.02	0.26	0.15	1	
Colony	0.21	−0.16	0.00	0.10	0.05	−0.06	0.32	0.00	−0.05	1

Table A3
Correlation results of Cameroon's wood-based panels.

	EXP	Dist	GDPi	GDPj	Rexch	ExchVol	Com lg	FLEGT	LAA	Colony
EXP	1									
Dist	−0.41	1								
GDPi	−0.08	−0.001	1							
GDPj	0.05	0.465	0.12	1						
Rexch	0.01	0.005	0.07	0.25	1					
ExchVol	−0.25	0.337	−0.03	0.13	−0.05	1				
Com lg	−0.07	0.129	0.001	0.21	0.14	−0.13	1			
FLEGT	−0.05	−0.002	0.80	0.08	0.03	0.00	0.003	1		
LAA	0.05	0.139	0.17	0.39	0.05	−0.03	0.25	0.15	1	
Colony	0.12	−0.170	−0.01	0.09	0.02	−0.08	0.37	0.001	−0.052	1

Table A4
Correlation results of Ghana's industrial roundwood.

	EXP	Dist	GDPi	GDPj	Rexch	ExchVol	Com lg	FLEGT	LAA	Colony
EXP	1									
Dist	−0.37	1								
GDPi	−0.07	0.001	1							
GDPj	0.03	0.47	0.16	1						
Rexch	0.19	−0.01	0.04	0.39	1					
ExchVol	0.23	0.25	−0.02	0.06	−0.13	1				
Com lg	0.29	0.08	0.00	−0.09	0.22	0.00	1			
FLEGT	−0.08	−0.003	0.89	0.13	0.01	0.08	0.00	1		
LAA	−0.21	0.20	0.23	0.43	0.01	−0.06	0.25	0.24	1	
Colony	0.05	−0.29	0.00	0.08	0.42	0.04	0.38	0.00	−0.10	1

Table A5
Correlation results of Ghana's sawnwood.

	EXP	Dist	GDPi	GDPj	Rexch	ExchVol	Com lg	FLEGT	LAA	Colony
EXP	1									
Dist	−0.11	1								
GDPi	−0.47	0.00	1							
GDPj	0.28	0.50	0.10	1						
Rexch	0.35	−0.13	0.00	0.28	1					
ExchVol	−0.05	0.25	−0.03	0.13	−0.16	1				
Com lg	0.07	0.23	−0.007	0.02	0.09	0.03	1			
FLEGT	−0.49	0.00	0.89	0.08	0.00	0.04	−0.004	1		
LAA	0.10	0.12	0.16	0.37	0.08	−0.02	0.26	0.17	1	
Colony	0.08	−0.10	−0.002	0.16	0.33	0.06	0.38	0.002	−0.05	1

Table A6
Correlation results of Ghana's wood-based panels.

Probability	EXP	Dist	GDPi	GDPj	Rexch	ExchVol	Com lg	FLEGT	LAA	Colony
EXP	1									
Dist	−0.10	1								
GDPi	−0.47	0.00	1							
GDPj	0.24	0.34	0.11	1						
Rexch	0.17	−0.21	0.15	0.34	1					
ExchVol	−0.12	0.17	0.02	0.16	−0.11	1				
Com lg	0.15	0.55	0.00	0.39	0.07	0.05	1			
FLEGT	−0.45	0.00	0.89	0.09	0.11	0.09	0.00	1		
LAA	−0.07	0.14	0.17	0.42	0.08	0.00	0.30	0.18	1	
Colony	−0.03	−0.14	0.00	0.16	0.36	0.09	0.44	0.00	−0.05	1

Table A7
Correlation results of the Republic of Congo's industrial roundwood.

	EXP	Dist	GDPi	GDPj	Rexch	ExchVol	Com lg	FLEGT	Colony
EXP	1								
Dist	0.19	1							
GDPi	−0.07	0.00	1						
GDPj	0.29	0.61	0.15	1					
Rexch	0.01	0.03	0.09	0.26	1				
ExchVol	0.05	0.35	−0.04	0.25	−0.12	1			
Com lg	0.09	−0.13	0.004	−0.15	0.01	−0.12	1		
FLEGT	−0.06	0.00	0.65	0.11	−0.01	0.03	−0.003	1	
Colony	0.25	−0.10	0.001	0.16	0.02	−0.06	0.67	−0.001	1

Table A8
Correlation results of the Republic of Congo's sawnwood.

	EXP	Dist	GDPi	GDPj	Rexch	ExchVol	Com lg	FLEGT	LAA	Colony
EXP	1									
Dist	−0.22	1								
GDPi	0.13	0.00	1							
GDPj	0.16	0.59	0.11	1						
Rexch	0.26	−0.01	0.09	0.28	1					
ExchVol	−0.08	0.23	−0.02	0.21	−0.15	1				
Com lg	0.12	0.07	0.00	−0.12	−0.09	−0.11	1			
FLEGT	−0.12	0.00	0.65	0.08	−0.05	0.06	0.00	1		
LAA	0.20	0.22	0.17	0.39	0.08	−0.01	−0.09	0.11	1	
Colony	0.28	−0.14	0.00	0.11	0.05	−0.04	0.53	0.002	−0.05	1

Table A9
Correlation results of the Republic of Congo's wood-based panels.

	EXP	Dist	GDPi	GDPj	Rexch	ExchVol	Com lg	FLEGT	LAA	Colony
EXP	1									
Dist	−0.20	1								
GDPi	−0.06	0.00	1							
GDPj	0.02	0.44	0.11	1						
Rexch	0.12	−0.07	0.20	0.27	1					
ExchVol	−0.10	0.16	−0.05	0.11	−0.14	1				
Com lg	0.21	−0.01	−0.00	−0.07	−0.06	−0.10	1			
FLEGT	−0.07	−0.00	0.65	0.07	0.02	0.05	−0.00	1		
LAA	0.14	0.17	0.17	0.43	0.10	0.00	−0.10	0.12	1	
Colony	0.35	−0.16	−0.00	0.14	0.08	−0.03	0.53	0.00	−0.05	1

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.forpol.2024.103262.

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