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US imports of softwood lumber: Assessing the significance of spillover effects

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ABSTRACT

Moving beyond the traditional focus on U.S.-Canada trade, this study employs the Spatial Durbin Model (SDM) to explore the broader dynamics of softwood lumber imports. A key contribution of this research is the recognition of spatial spillover effects, revealing the influence of third-country exporters on U.S. softwood lumber imports. The positive spatial dependence coefficient suggests that countries exporting softwood lumber to the U.S. stimulate their neighbors to follow suit, emphasizing the importance of accounting for spatial interdependencies in wood products trade analysis. These findings carry significant policy implications. Policymakers must adapt to the evolving global trade landscape, acknowledging the increasing diversity of softwood lumber suppliers. Consideration of tariffs, language barriers, and geographic factors in trade policies is imperative. Furthermore, the potential for establishing regional hubs for softwood lumber sourcing is highlighted, offering opportunities to enhance supply chain resilience and sustainability.

1. Introduction

In the context of the circular bioeconomy, which emphasizes the sustainable utilization of renewable resources, softwood lumber—commonly referred to as coniferous sawnwood in FAO's terminology—has emerged as one of the most economically significant wood products globally, both in terms of its production volume and economic impact (European Commission, 2018). For instance, as a construction material, softwood lumber boasts attributes such as energy efficiency, carbon storage capacity, and cost-effectiveness, making it a highly desirable choice when compared to alternative materials (Raunikar et al., 2010; Skjerstad et al., 2021).

A quick glance at Table 1 provides a glimpse of the paramount importance of softwood lumber within the United States.

In 2019, the United States stood out as the leading producer, contributing a substantial 60.04 million cubic meters, while also ranking as a major importer, bringing in 24.53 million cubic meters of softwood lumber. This substantial volume of imports and production signifies the United States' pivotal role in the softwood lumber industry. Impressively, these quantities represent approximately 20% of the total global availability of softwood lumber.

Two additional observations can be derived from Table 1. Firstly, the data reveal that the top 10 countries collectively contribute to over 58% of the global supply of softwood lumber. This underscores their dominant role in the global softwood lumber market. Secondly, it is worth noting that numerous other nations also maintain a surplus in their softwood lumber accounts, indicating their potential to serve as significant suppliers to the U.S. market. Traditionally, Canada has been the predominant exporter of softwood lumber to the U.S. However, the increasing interconnectedness of global economies brought about by globalization has led to a steady rise in U.S. imports from countries such as Chile, Germany, New Zealand, and Sweden in recent years (Xiang and Yin, 2006). Despite the significance of softwood lumber in US wood products trade,

most existing studies have primarily focused on U.S. imports from Canada, rather than taking a comprehensive and broader approach to the issues surrounding U.S. imports from the rest of the world (Zhang, 2007). Broadly speaking, earlier research has investigated the implications of various trade restrictions on Canadian softwood lumber, examined the effects of exchange rate and price dynamics on the competitiveness of the U.S. softwood lumber industry.

For instance, Buongiorno et al. (1988) and Sarker (1996) have found that changes in U.S. lumber prices, disposable income, and housing starts significantly influence Canadian lumber exports to the U.S. These findings underscore the critical role of domestic economic conditions in driving the demand for lumber imports from Canada.

Furthermore, the impact of exchange rates on U.S. lumber trade has been examined in studies like those conducted by Adams et al. (1986)

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Table 1
Top 10 softwood lumber consumers in 2019 (millions of m3).

Country	Production	Import Quantity	Export Quantity	Consumption
United States of America	60.04	24.53	2.31	82.26
China	40.21	28.62	0.08	68.75
Germany	23.31	4.87	8.89	19.29
Canada	40.79	0.65	27.43	14.01
Japan	8.28	5.51	0.14	13.65
Russia	41.27	0.04	31.47	9.83
United Kingdom	3.41	6.44	0.19	9.65
France	6.56	2.48	0.94	8.10
Sweden	18.63	0.47	12.60	6.50
Türkiye	5.92	0.38	0.10	6.20

Source: FAOSTAT.

and Zhang (2001). These researchers have revealed that while exchange rates can influence trade dynamics to some extent, their effects are outweighed by other macroeconomic factors. Additionally, trade liberalization has been studied by Gan and Ganguli (2003) and Gan (2004), who found that it has boosted U.S. forest product exports to emerging markets in Asia and Latin America, highlighting the transformative effect of changes in trade policies on U.S. lumber trade patterns.

Moreover, the significance of non-tariff barriers and timber export policies has been analyzed by Sun et al. (2010); van Kooten and Johnston (2014); Muhammad and Jones (2021); Brusselaers and Buysse (2021); and Pan et al. (2021), shedding light on how trade restrictions and tariffs can significantly impact welfare and trade patterns. These restrictions are likely to continue owing to the emergence of newer motivations in the form of climate change mitigation targets whereby improved forest management and increased use of wood products provide a long-term solution to enhance carbon sequestration (Zhai and Kuusela, 2022).

Additionally, Zhang and Li (2009) delved into the influence of timber resource endowments on net exports of forest products, revealing a mixed picture, with some studies showing a strong positive relationship and others indicating a limited impact. Finally, Xiang and Yin (2006) investigated the effects of globalization and policy changes on U.S. softwood lumber trade. Their research provided a comprehensive analysis of how global trends and policy shifts influenced the U.S. lumber trade landscape, offering insight into the drivers of change in the industry.

Despite the valuable contributions of existing studies in initiating the debate and shaping our understanding of the complex interplay of factors affecting U.S. imports of softwood lumber, some limitations can be attributed to most of the existing literature, potentially affecting the accuracy of their conclusions. Many previous studies focused on a two-country model to analyze U.S.- Canada trade, an approach that raises significant methodological considerations given the declining relative importance of U.S. imports of softwood lumber from Canada in recent years. This modeling approach disregards the possibility of trade diversions due to the presence of new suppliers from Europe, Asia, and Latin America.

Another crucial aspect often overlooked in forest products trade, including softwood lumber, is the consideration of spatial spillover effects. Spatial spillover occurs when an event in one region influences other regions (Capello, 2009). This phenomenon is common in international trade and has been studied in various fields (Boubacar, 2016). However, in the context of forest products trade, including softwood lumber, the impact of spatial spillover remains unexplored.[1] The widely used gravity model of trade fails to capture spatial interconnections and interactions among trade activities and partners (LeSage and Pace, 2009; LeSage and Llano-Verduras, 2014). Incorporating spatial spillover considerations into trade models can lead to more accurate and robust estimates of the determinants of forest products trade flows. Our paper will contribute to the literature by addressing this gap. Undoubtedly, the emergence of new trading partners is likely to result in increased spatial interconnectivity of trade flows among the origin countries of U.S. imports of softwood lumber (LeSage and Pace, 2009), a phenomenon that cannot be adequately accounted for using a simple two-country trade model.

While numerous studies have focused on US softwood lumber imports, to our knowledge, none has specifically examined the spatial spillover effects or the marginal impacts of individual determinants, considering spatial influences. Furthermore, there has been no detailed breakdown of the total effect. Therefore, the primary objective of this research is to empirically analyze the spatial spillover effects of the underlying factors in US softwood lumber import using the spatial Durbin model (SDM).

The effect decomposition of determinants enables us to estimate their spillover and other effects on import while allowing for spatial dependence, a major contribution of this study to the existing literature. Our findings provide new insights into softwood lumber trade and its principal determinants from the view of spatial autocorrelation, and suggest that allowing for spatial spillover effects, a change in a given factor in one country can exert an increasingly significant influence on trade flows as its neighboring and other countries react. The complex spatial interconnectivity warrants strong regional cooperation in forest policy management.

2. Methodology

2.1. Model specification

As the world economies are becoming increasingly open and interconnected, international trade flows of forest products are intensifying and continuously leading to spatial spillover. The standard model used in trade literature, the gravity model, is not designed to capture spillover effects because it assumes independence among trade flows. To evaluate the extent of spatial interconnections among the trading partners involved in U.S. softwood lumber imports, we adopt the methodology proposed by LeSage and Pace (2009), which involves specifying the following spatial Durbin model (SDM).

$$\mathrm{Y} = \rho \mathrm{WY} + \alpha \iota + X\beta + WX\theta + \varepsilon, \tag{1}$$

with $\varepsilon \sim \mathrm{N}(0_{n\times 1}, \sigma^2 \mathrm{I}_n)$, $t = 1997, \ldots, 2017$, $n = 1,2,3, \ldots 24$;

The matrix W is a non-stochastic and non-negative n by n weight matrix.

Its elements are used to specify the spatial dependence structure among the observations. The common practice in the literature is to row-normalize the weight matrix W.[2] Furthermore, if observation country i is related to observation j, then $\omega_{ij} > 0$, and $\omega_{ij} = 0$ otherwise. For this study, the elements of the weight matrix W are computed as follows:

$$\omega_{ij} = \begin{cases} \dfrac{1}{d_{ij}} \text{ when } i \neq j \\ 0 \text{ when } i = j \end{cases}, \tag{2}$$

d_{ij} measures the distance between each pair of capital cities of countries where the US imports its softwood lumber. Where the column vector of dependent variables Y is an (n by 1) vector of log-transformed U.S. import values of softwood lumber from its trading partner i in year t; WY is the spatially lagged term reflecting the origin-to-origin dependence to capture the extent of the spatial interaction among US trading

[1] Yin et al. (2020) being an exception. However, their study was based on a cross-sectional data of total forest wood product trade.

[2] Row-sums of unity and zeros on the main diagonal of the matrix.

partners, with the intensity of the dependence measured by ρ. X is an (n by k) matrix of observations on the explanatory variables associated with US, its trading partners, and both the US and its trading partners. The matrix WX represents a linear combination of explanatory variables from related countries. The spatially lagged dependent variable accounts for the spatial spillover effects among US trading partners. Hence, the use of SDM to analyze the dependence of trade flows.

Lesage and Pace (2009) provide theoretical evidence suggesting that SDM encompasses commonly specified models in applied spatial econometrics. In effect, (i) when $\theta = 0$, Eq. (1) becomes a spatial autoregressive model that includes spatial lags of US imports of softwood lumber from its trading partners, but excludes trading partners characteristics that enhance softwood lumber trading from neighboring countries to exert an influence on lumber exports of a given country i; (ii) when $\theta = -\rho\beta$, Eq. (1) becomes a spatial error model; and finally (iii) when $\theta = 0$ *and* $\rho = 0$, Eq. (1) specifies the standard gravity model used in the traditional trade literature. It becomes clear that the gravity model is a special case of SDM specified in Eq. (1) that assumes a lack of dependence among countries' dependent variables and characteristics.

For a sample of 24 countries, Eq. (1) can be rewritten as (LeSage and Fischer, 2008):

$$Y = \sum_{i=1}^{i=24} K_i(W)X_i + (I_n - \rho W)^{-1}\iota_n\alpha + (I_n - \rho W)^{-1}\varepsilon, \tag{3}$$

where $K_i(W) = (I_n - \rho W)^{-1}$ $(I_n\beta_i + W\theta_i)$.

LeSage and Fischer (2009)[3] argue that the standard regression interpretation of estimated parameters as partial derivatives describing the magnitude of changes in yi that arise from changes in xir is no longer valid in the case of SDM. Thus, they propose a series of metrics to interpret estimates from Eq. (3); direct, indirect, and total marginal effects of the determinants of US softwood lumber imports. Specifically, the direct effects are the impact on the value of softwood lumber import from a partner country i, given a change in one of the explanatory variables associated with the same country. In comparison, the indirect effects, also known as the spatial spillovers, measure the impact on the value of softwood lumber import from a partner country i arising from a change in a given determinant associated with its neighbors.

2.2. Data sources and description of variables

This study covers the period from 1997 to 2017. The selection of 1997 as the starting point is driven by our objective to consider significant trading partners beyond Canada, including countries from the former Soviet Union and China, which joined the World Trade Organization during this timeframe. We limit the sample to 24 countries because of data availability. The countries are listed in Table 2.

The dependent variable, Y, is a vector of log transformed volumes of US imports of softwood lumber from its 24 trading partners. The softwood lumber import volumes were derived from FAOSTAT and expressed in thousands of US dollars. US imports of softwood lumber, the dependent variable in this study, can be influenced by a variety of factors including those commonly associated with general international trade (e.g. gravity-type variables such as distance and income) as well as those specifically pertinent to forest product markets and trade (e.g. timber resource endowment, and tariffs).

Gross Domestic Product (GDP), a vital indicator for measuring the economic size of a country, plays a pivotal role in shaping international trade. Larger economies, as indicated by higher GDPs, are expected to engage in more substantial exports and/or imports. We use GDP to assess the impact of the economic size of the 24 key countries that export softwood lumber to the United States.

[3] Interested readers can refer to (LeSage and Fischer, 2009) for mathematical derivations of direct, indirect, and total effects that could be obtained from taking partial derivatives of Eq. (3).

Table 2
List of countries.

Country	Continent	Country	Continent
Argentina	Americas	Honduras	Americas
Australia	Oceania	Italy	Europe
Austria	Europe	Latvia	Europe
Brazil	Americas	Lithuania	Europe
Canada	Americas	Mexico	Americas
Chile	Americas	Netherlands	Europe
China	Asia	New Zeeland	Oceania
Czechia	Europe	Russia	Europe
Estonia	Europe	Sweden	Europe
Finland	Europe	Switzerland	Europe
France	Europe	United Kingdom	Europe
Germany	Europe	Uruguay	Americas

Forest resource endowment: According to the Heckscher-Ohlin (H—O) framework, which explores the relationship between production location and consumption patterns, resource endowments significantly influence trade flows (Nasrullah et al., 2020). The H—O theory posits that countries with abundant resources are inclined to export more, while those with scarce resources tend to import products. In this study, we use the volume of roundwood production per capita as a proxy for a country's forest resource endowment.

Tariffs: Tariffs are often implemented to restrict imports and safeguard domestic markets (Zhang et al., 2021). In developing countries, they also serve as sources of government revenue. We use the weighted average of effectively applied rates by the product import shares corresponding to each partner country (Yin et al., 2020).

Language: A shared language between the United States and its trading partners is used as a proxy for cultural similarity. Previous studies have indicated that a common language can enhance trade flows, while language barriers can hinder them. However, it is worth noting that in the era of technological advancement, this traditional determinant of international trade may become less significant. We use a dummy variable, set to 1, to indicate whether a trading partner's official language is English; otherwise, it is equal to 0.

Landlocked: Sea transportation is a cost-effective means for the long-distance shipment of forest products. Countries without access to the ocean may face increased transportation costs, potentially impeding international trade. We use a dummy variable, set to 1 for landlocked countries and 0 for others, to account for this factor.

Distance: In this context, the transportation distance between the US and its trading partners serves as a proxy for transportation costs, considering that longer distances can impede international trade. The transportation distance is calculated as the great-circle distance between the capitals of the US and any of its trading partners.

The descriptions and measurements of the dependent and independent variables are summarized in Tables 3 and 4.

Table 4 presents the basic descriptive statistics of sample data.

3. Results and analysis

3.1. Cointegration test

An implicit assumption regarding Eq. (1) is that, in the long run, permanent changes in US import of softwood lumber are associated with the set of explanatory variables as per our modeling framework. The empirical implication is that these variables must be nonstationary, that is the regressors ought to be correlated with the dependent variable. Thus, one of the most widely used panel unit root test, namely Im, Pesaranand Shin (Im et al., 2003) test, is used in this study. All the variables are tested in their natural logarithmic forms and the results are summarized in Table 5. The results suggest that the variables follow nonstationary stochastic processes. Consequently, we can proceed with our model estimations since we establish empirical evidence that rules out the existence of spurious relationships between US import of

Table 3
Variables and data sources.

Variable	Definition	Unit	Symbol	Data source
Import quantity	The log of import volume of US softwood lumber from the origin country	Cubic meter (m3)	Y	USDA/FAS
Gross Domestic Product	The log of gross domestic product	Constant 2015 US$ trillion	USGDP for the US, and OGDP for the origin country	World Bank
landlocked	Dummy variable for landlocked origin country	–	Ldl	CPII
Language	Dummy variable for having English as the official language	–	Lng	CIA's website
Forest resource endowments	The log of roundwood production per capita	Cubic meter (m3)	USfre for the US, and Ofre for the origin country	FAO/World Bank
Tariffs	Weighted average of effectively applied rates by the product import shares corresponding to each partner country.	%	Trf	World Bank / WTO
Income	The Log of per capita gross national income	Constant 2015 US$	USpcgni for the US and Opcgni for origin country	World Bank

Notes: Log refers to natural logarithm.
CEPII refers to Centre d'Etudes Prospectives et d'Informations Internationales.
CIA refers to the Central Intelligence Agency.
WTO refers to World Trade Organization.
FAO refers to Food and Agriculture Organization of the United Nations.
USDA: United State Department of Agriculture.
FAS: Foreign Agricultural Service.

Table 4
Descriptive Statistics.

Variable	Observation	Minimum	Mean	Maximum	Standard deviation
Lumber	504	1.010	1.599 million	50.4 million	7,422,021
USGDP	504	12.070	15.729	18.925	1.901
OGDP	504	0.011	1.021	12.640	1.558
USPCGNI	504	44,118	52,554	59,625	3974
OPCGNI	504	1645	26,354	86,897	19,552
USfre	504	1.430	1.084	1.703	0.188
Ofre	504	0.052	2.477	11.488	2.708
Otariff	504	1.25	7.692	29.15	3.998
Landlocked	504	0	0.125	1	0.331
Language	504	0	0.165	1	0.371
Distance	504	737	7309	15,962	3086

Table 5
Im-Pesaran-Shin panel unit-root test.

Variable	Level
Log of softwood lumber import quantity	−3.7874***
Log of US GDP	−4.1982***
Log of Partners GDP	−3.7620***
Log of Partners Forest Resource Endowment	−3.2135***
Log of US Forest Resource Endowment	−4.6220***
Tariffs	−5.4460***
Log of Partners Per Capita income	−2.8115**
Log of US Per Capita income	0.3275

Notes: *, **, and *** indicate statistical significance at 10%, 5%, and 1% levels, respectively.
Log stands for natural log.

softwood lumber and its determinants.

3.2. Spatial correlation test

In what is known as Tobler's first law of geography, "Everything is related to everything else, but near things are more related than distant things." (Tobler, 1970). From a statistical standpoint, the statement highlights the influence of space on data. More specifically, proximity leads to spatial correlation among variables. Moran's index is the classical statistical test used to assess the existence of spatial correlation. We therefore use the global Moran's index to statistically test the spatial correlation of US softwood lumber imports before conducting our spatial econometric analysis. Table 6 summarizes the results of the tests.

The general observation that can be derived from Table 6 is that the Moran's index is statistically positively significant in most years. This consistent positive spatial correlation of US softwood lumber imports lends support to the existence of agglomeration effects.

3.3. Baseline results

The baseline model, Eq. (1) above, contains the spatial lag term of the dependent variable (WY). Thus, the ordinary least squares estimation will produce inconsistent and biased results. We therefore follow the existing literature (LeSage and Pace, 2009; Chen et al., 2022; and Yin et al., 2020) to adopt the maximum likelihood method to estimate to estimate the spatial Durbin model specified in Eq. (1). To put our results into perspective, we also provide the estimation results of the non-spatial fixed effect (FE) and generalized method of moment (GMM) models. These results are summarized in Table 7.

Models 1 and 2 in Table 7 show the estimation results of the FE and GMM methods, respectively. The two estimation methods yield similar results in terms of their relationship with the basic gravity model of

Table 6
Global Moran's index of Softwood lumber import.

Year	1997	1998	1999	2000	2001	2002	2003
Value	0.432*	0.271*	0.272*	0.271	0.301	0.172*	0.324*
	(1.88)	(1.74)	(1.84)	(1.24)	(1.40)	(1.87)	(1.74)
Year	2004	2005	2006	2007	2008	2009	2010
Value	0.402*	0.159*	0.055**	0.076*	−0.010	0.204***	0.117**
	(1.75)	(1.79)	(2.39)	(1.76)	(0.13)	(2.97)	(2.64)
Year	2011	2012	2013	2014	2015	2016	2017
Value	0.218*	0.455**	−0.043	0.176*	0.221*	0.320*	0.180**
	(1.94)	(1.99)	(0.001)	(1.87)	(1.85)	(1.84)	(2.09)

Notes: T Stats of Moran's I value are in parentheses; *, **, and *** indicate statistically significance at 10%, 5%, and 1% levels, respectively.

Table 7
Estimation results of Eq. (1) based on the FE model, dynamic GMM, and SDM.

Variable	Model 1 Fixed Effects	Model 2 Dynamic GMM	Model 3 SDM (W1)	Model 4 SDM (W2)
Lag Y	–	0.446*** (0.049)	–	–
WY	–	–	0.338*** (0.082)	0.335*** (0.082)
USGDP	4.653*** (1.238)	5.961*** (1.288)	2.706* (1.458)	2.666* (1.478)
OGDP	0.592* (0.352)	0.909** (0.387)	0.398** (1.134)	0.394* (1.351)
USpcgni	−0.086 (0.104)	−0.093 (0.091)	0.061* (1.010)	0.061* (1.100)
Opcgni	−0.604 (0.510)	−2.925*** (0.624)	−0.154** (0.529)	−0.132** (0.532)
USfre	0.961*** (1.095)	44.007*** (1.444)	6.587*** (0.299)	6.589*** (0.283)
Ofre	9.148*** (0.294)	−0.054 (0.325)	1.111*** (1.176)	1.098*** (1.299)
Trf	0.997 (0.039)	1.010 (0.045)	−0.025* (1.380)	−0.025* (1.388)
Ldl	0.822 (1.672)	0.672 (0.908)	−0.584* (0.792)	−0.660* (0.799)
Lng	0.949 (1.556)	0.214 (1.444)	−0.718 (1.436)	−0.734 (1.437)
Dst	−1.751* (0.935)	−0.101 (1.461)	−1.692** (0.755)	−1.788** (0.754)
WOGDP	–	–	1.008* (0.740)	1.050* (0.732)
WOpcgni	–	–	−0.473* (0.287)	−0.440*
WOfre	–	–	0.297** (0.504)	0.218** (0.559)
WTrf	–	–	0.150* (0.205)	0.147* (0.275)
WLdl	–	–	5.971 (11.144)	7.291 (11.224)
WLng	–	–	−15.963 (17.587)	−21.01 (17.465)
Intercept	15.66 (9.834)	18.891 (15.981)	18.125*** (9.010)	18.946** (8.924)
Log likelihood			−746.65	−746.88
Likelihood ratio test $\chi 2$			153.23***	152.64***
Wald test $\chi 2$	108.39***	247.37***	28.83***	28.27***

Notes: The standard errors of coefficients are in parentheses; *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.
GMM: Generalized Method of Moments.
FE: Fixed effect
W1 is an inverse distance matrix with the sample median distance used as a cut-off point.
W2 is an inverse distance matrix without a cut-off point.
WY: Spatially lagged term of the dependent variable
Lag Y: 1 year lag value of the dependent variable
All the other symbols are as described in Table 3.

international trade. As can be seen from the table, the variables distance and GDP are statistically significant with signs consistent with the prediction of the basic gravity model of international trade. However, the reminder of the estimated coefficients are either statistically non-significant or are in sharp contrast with economic theories. For example, as pe the results from models 1 and 2, the estimated coefficient of the variable tariff is positive and statistically not significant. Moreover, the estimated coefficient of the variable US resources endowment is positively statistically significant, violating H—O theory. More importantly, the non-spatial panel FE and GMM estimations method present a major statistical issue, i.e., they fail to account for the spatial correlation among US trading partners, which ignores the statistical significance of the global Moran's I tests (Table 6).

Models 3 and 4 in Table 7 show the estimation results of the spatial Durbin model (SDM) through the MLE method with the spatial weights matrices of W1, and W2, respectively. Despite the use of different spatial weights matrices, the estimates from both models are quite similar in terms of their economic and statistical significance, indicating the robustness of our estimation results. Both the Likelihood- Ratio (LR) test and the Wald test lend strong support to our choice of the SDM. The Wald tests reject the hypotheses that the spatial lags of explanatory variables and spatial lag dependence of US softwood lumber imports do not exist. Therefore, the results will be biased should the spatial correlation be ignored.

A further analysis of Table 7 reveals that most of the estimated coefficients in the Spatial Durbin Model (SDM) are highly statistically significant, and their respective signs align with the predictions of international trade theory. Specifically, the coefficient estimates for the market size of the United States and its 24 trading partners are consistent with typical results from the gravity equation, as observed in previous studies on aggregate trade flows. For instance, the coefficient for U.S. GDP is statistically significant at the 10% level, valued at 2.706 and 2.666 in model 3 and 4, respectively. The results indicate that the United States, with its substantial market size, has the capacity to absorb more imports of softwood lumber.

Wood products play a pivotal role as raw materials in the construction, manufacturing, and shipping sectors of the U.S. economy. Despite its abundant forest resources and significant production capabilities, the United States relies on imports to meet its domestic wood product demand. This explains the seemingly surprising positive coefficient of the forest resources endowment variable (USfre). In essence, this result contradicts the predictions of the Heckscher-Ohlin (H—O) framework, which suggests that countries rich in timber resources tend to export more forest products, while those with limited timber resources tend to import more. However, the coefficient for the Ofre variable, representing the forest resource endowment of U.S. trading partners, aligns with the H—O framework. It is statistically significant at the 1% level, with a value of 1.111 and 1.098 in model 3 and 4, respectively.

It is important to note that imported lumber is only a partial substitute for domestically produced lumber (Buongiorno et al., 1979). Gross National Income (GNI) per capita is used as an indicator of the average income of producers in the exporting country and consumers in the importing country (Yin et al., 2020). Additionally, as explained by Bergstrand (1989), the income per capita of the exporting country tends to impact exports positively (negatively) if the commodity is capital (labor) intensive. On the other hand, the income per capita of the importing country tends to impact imports positively (negatively) if it is considered a necessity good (luxury). Our results show that the coefficient estimate for the USpcgni variable, representing U.S. per capita GNI, is statistically significant and negatively signed, indicating that softwood lumber is viewed as a necessity rather than a luxury commodity in the U.S. This finding aligns with existing literature on the income elasticity of softwood lumber demand (Skjerstad et al., 2021). Furthermore, the statistically negative coefficient for the Opcgni variable, representing the per capita GNI of U.S. trading partners and valued at −0.154 (Model 3) and − 0.132 (Model 4), supports the notion that softwood lumber is a labor-intensive commodity from the perspective of U.S. trading partners (Bergstrand, 1989).

Traditional non-activity variables, such as distance and the dummy variable for landlocked countries, have the expected negative coefficient signs and are statistically significant at the 5% and 10% levels, respectively. All else being equal, longer distances and a lack of access to an ocean discourage U.S. imports of softwood lumber, with longer distances having a more pronounced effect. However, the estimated coefficient for the variable language is unexpectedly positive, albeit not statistically significant. One plausible explanation for this result is the limited variation in the language variable, as only four out of the 24 countries have English as their official language. Thus, language barriers do not appear to hinder U.S. imports of softwood lumber from the sampled countries in our study.

The inclusion of spatially lagged terms in the model enables the

Spatial Durbin Model to reveal spatial interconnections among the trading partners involved in U.S. imports of softwood lumber. These spatial lag terms, WY, are both statistically and economically significant, providing evidence of third-country effects on U.S. softwood lumber imports. The spatial dependence among U.S. trading partners is statistically significant at the 1% level, with an estimated coefficient of 0.338 (Model 3) and 0.335 (Model 4). The positive sign of this coefficient suggests that a country exporting softwood lumber to the U.S. influences its neighboring countries to do the same. This robust spatial interdependence could potentially lead to the establishment of an active hub where the U.S. can source its softwood lumber to meet the growing demand for wood products.

One particular aspect of SDM is that the independent variables have circular feedback effects on the dependent variables of local and spatially related countries. We follow LeSage and Pace (2009); Elhorst (2014), and Yin et al. (2020) to estimate the direct and indirect effects of various explanatory variables included in our SDM specification. This decomposition method will allow us to isolate the marginal effects of local independent variables on the local dependent variable and spatially related countries' dependent variables, known as the direct effect and indirect effect, respectively. Given our sample of 24 countries and 10 explanatory variables, there would be 2400 marginal effects to report. To enhance practicality, we computed and presented the average marginal effects in Table 8.

A quick glance at Table 8 reveals that the results of Models 3 and 4, with respect to the various effects, are quite similar in terms of their economic and statistical significance. Thus, the discussion of our estimation results will be based off Model 3 of Table 8. As previously stated, the direct effect reflects the marginal effects of local independent variables on the local dependent variable. As shown in Model 3, all the variables are statistically significant at either 1%, 5%, or 10% levels, with signs consistent with economic theories. Furthermore, the indirect effect, which is also known as the spatial spillover effect, reflects the overall marginal effects of spatially related countries' independent variables on a given country's dependent variable. A major observation that can be derived from Table 8 is that the estimates of distance, language, landlocked, tariffs, exporting countries' forest resources endowment, and US per capita income variables are no longer statistically significant. This implies that these variables in spatially related countries do not present a spatial spillover effect in the region, ceteris paribus. In contrast, the estimated coefficients of USGDP, OGDP, Opcgni, USfre, and Dst are statistically significant. The results imply that changes in those variables in spatially related countries have a spillover effect in fostering US imports from the region (when the coefficient is positive) or hindering US imports from the region (when the coefficient is negative).

In terms of total effect, which is the sum of direct effect and indirect effect, all the coefficients are statistically significant except for landlocked and language variables. Additionally, it is worth noting that the total effects are relatively larger in absolute terms when compared to the direct effects for most variables. This observation underscores the significance of accounting for spatial effects in wood products trade analysis because neglecting to consider the spillover effects would lead to biased estimates.

4. Conclusion

This article provides a comprehensive analysis of the determinants of U.S. imports of softwood lumber, a key driver of sustainable resource utilization. Our objective was to move beyond the traditional focus on U.S.-Canada trade and examine the broader landscape of U.S. imports of softwood lumber from various countries worldwide. Our methodology, based on the Spatial Durbin Model (SDM), allowed us to account for spatial interdependencies and third-country effects, providing a more accurate representation of the factors influencing softwood lumber trade flows. Our results highlight several key findings:

Global Significance of Softwood Lumber: Softwood lumber is of paramount importance globally, with the United States emerging as a major player in both production and importation. The United States alone contributes significantly to the global supply, underlining its pivotal role in the softwood lumber industry.

Diverse Supplier Base: While Canada has traditionally been the primary supplier of softwood lumber to the United States, our analysis reveals an evolving landscape with the emergence of new trading partners. Countries in Europe, Asia, and Latin America are increasingly contributing to U.S. imports, reflecting the interconnectedness of global economies.

Spatial Spillover Effects: Incorporating spatial spillover considerations into our analysis has revealed the significance of third-country effects on U.S. softwood lumber imports. The positive spatial dependence coefficient suggests that a country exporting softwood lumber to the U.S. influences its neighboring countries to do the same. This

Table 8
Direct, indirect, and total effects of Models 3 and 4 in Table 7.

Variable	Direct effect		Indirect effect		Total effect	
	Model 3	Model 4	Model 3	Model 4	Model 3	Model 4
USGDP	2.739*	2.698*	0.724*	0.727*	3.463*	3.425*
	(1.471)	(1.491)	(0.403)	(0.414)	(1.843)	(1.842)
OGDP	0.440*	0.438*	0.905*	0.963*	1.345*	1.401*
	(1.356)	(1.359)	(0.571)	(0.507)	(1.823)	(1.802)
USpcgni	0.062*	0.062*	−0.016	−0.017	0.046*	0.045**
	(1.313)	(1.110)	(0.026)	(0.027)	(1.826)	(2.182)
Opcgni	−0.174*	−0.149**	−0.417*	−0.395	−0.591*	−0.544*
	(0.334)	(0.237)	(0.457)	(0. 265)	(0.376)	(0.485)
USfre	−1.135***	−1.120**	0.533***	0.477***	−0.602***	−0.643***
	(0.299)	(0.220)	(0.568)	(0.581)	(1.381)	(1.389)
Ofre	6.668***	6.669***	1.764	1.798	8.432*	8.467*
	(1.173)	(1.179)	(0.822)	(0. 851)	(0. 893)	(0.922)
Trf	−0.979*	−0.021**	1.119	1.119	−0.860*	0.098
	(0.589)	(0.389)	(0.0796)	(0. 0824)	(0.398)	(0.933)
Ldl	−0.511*	−0.437*	4.494	5.645	3.983	5.208
	(0.611)	(0.615)	(8.568)	(8.8785)	(8.127)	(8.411)
Lng	0.155**	0.122**	1.983	1.478*	2.138	1.600
	(1.729)	(1.738)	(14.08)	(0.437)	(15.18)	(15.55)
Dst	−1.713**	−1.809**	−0.452*	−0.488**	−2.165**	−2.297**
	(0.765)	(0.764)	(0. 257)	(0. 268)	(0.983)	(0.988)

Notes: The standard errors of coefficients are in parentheses; *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. All the other symbols are as described in Table 3.

underscores the importance of considering spatial effects in wood products trade analysis.

Policy Implications: Our results have important policy implications. Policymakers should recognize the evolving landscape of softwood lumber trade and consider the diverse set of trading partners. Economic and geographical factors play a role in trade dynamics and should be taken into account when formulating trade policies. Furthermore, the positive spatial interdependence observed suggests the potential for establishing regional hubs for softwood lumber sourcing, which could enhance supply chain resilience and sustainability.

In conclusion, our study provides a comprehensive understanding of the determinants of U.S. imports of softwood lumber, emphasizing the importance of considering spatial interdependencies and the evolving global trade landscape. Policymakers and industry stakeholders can use these insights to make informed decisions that promote sustainability and resilience in the softwood lumber sector. Further research in this field could delve deeper into the specific mechanisms driving spatial spillover effects and explore strategies for optimizing the softwood lumber supply chain in a rapidly changing global economy.

CRediT authorship contribution statement

Inoussa Boubacar: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

References

Adams, D.M., Mccarl, B.A., Homayounfarrokh, L., 1986. The role of exchange rates in Canadian-United States lumber trade. For. Sci. 32, 973–988.
Bergstrand, J.H., 1989. The generalized gravity equation, monopolistic competition, and the factor-proportions theory in international trade. Rev. Econ. Stat. 71 (1), 143–153.
Boubacar, I., 2016. Spatial determinants of U.S. FDI and exports in OECD countries. Econ. Syst. 40 (1), 135–144.
Brusselaers, J., Buysse, J., 2021. Legality requirements for wood import in the EU: who wins, who loses? Forest Policy Econ. 123, 102338.
Buongiorno, J., Chou, J.-J., Stone, R.N., 1979. A monthly model of the United States demand for softwood lumber imports. For. Sci. 25 (4), 641–655.
Buongiorno, J., Chavas, J.-P., Uusivouri, J., 1988. Exchange rates, Canadian lumber imports, and United States prices: a time-series analysis. Can. J. For. Res. 18, 1587–1594.
Capello, R., 2009. Spatial spillovers and regional growth: a cognitive approach. Eur. Plan. Stud. 17 (5), 639–658.
Chen, Y., Shao, S., Meiting Fan, M., Zhihua Tian, Z., Yang, L., 2022. One man's loss is another's gain: does clean energy development reduce CO2 emissions in China? Evidence based on the spatial Durbin model. Energy Econ. 107, 105852.
Elhorst, J.P., 2014. Spatial Econometrics: From Cross-Sectional Data to Spatial Panels. Springer, Heidelberg.
European Commission, 2018. A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment. Updated Bioeconomy Strategy. Directorate-General for Research and Innovation, Brussels, Belgium, 107 p.
Gan, J., 2004. Effects of China's WTO accession on global forest product trade. Forest Policy Econ. 6, 509–519.
Gan, J., Ganguli, S., 2003. Effects of global trade liberalization on U.S. forest products industries and trade: a computable general equilibrium analysis. For. Prod. J. 53 (4), 29–35.
Im, K.S., Pesaran, M.H., Shin, Y., 2003. Testing for unit roots in heterogeneous panels. J. Econ. 115 (1), 53–74.
LeSage, J.P., Fischer, M.M., 2008. Spatial growth regressions: model specification, estimation and interpretation. Spat. Econ. Anal. 3 (3), 275–304.
LeSage, J.P., Fischer, M.M., 2009. Spatial econometric methods for modeling origin-destination flows. In: Fischer, M.M., Getis, A. (Eds.), Handbook of Applied Spatial Analysis. Springer, Berlin, Heidelberg and New York, pp. 409–433.
LeSage, J.P., Llano-Verduras, C., 2014. Forecasting spatially dependent origin and destination commodity flows. Empir. Econ. 47 (4), 1543–1562.
LeSage, J.P., Pace, R.K., 2009. Introduction to Spatial Econometrics. Taylor and Francis–CRC Press, New York.
Muhammad, A., Jones, K.G., 2021. The end of the trade war? Effects of tariff exclusions on U.S. forest products in China. Forest Policy Econ. 122, 102350.
Nasrullah, M., Changa, L., Khana, K., Rizwanullah, M., Zulfiqar, F., Ishfaq, M., 2020. Determinants of forest product group trade by gravity model approach: a case study of China. Forest Policy Econ. 113, 102117.
Pan, W., Chang, W.Y., Wu, T., Zhang, H., Ning, Z., Hongqiang Yang, H., 2021. Impacts of the China-US trade restrictions on the global forest sector: a bilateral trade flow analysis. Forest Policy Econ. 123, 102375.
Raunikar, R., Buongiorno, J., Turner, J.A., Zhu, S., 2010. Global outlook for wood and forests with the bioenergy demand implied by scenarios of the intergovernmental panel on climate change. Forest Policy Econ. 12 (1), 48–56.
Sarker, R., 1996. Canadian softwood lumber export to the US: a cointegrated and error corrected system. J. For. Econ. 2, 205–231.
Skjerstad, S.H.F., Kallio, A.M.I., Bergland, O., Solberg, B., 2021. New elasticities and projections of global demand for coniferous sawnwood. Forest Policy Econ. 122, 102336.
Sun, L., Bogdanski, B., Stennes, B., van Kooten, G.C., 2010. Impacts of tariff and non-tariff trade barriers on the global forest products trade: an application of the global Forest product model. Int. For. Rev. 12 (1), 49–65.
Tobler, W., 1970. A computer movie simulating urban growth in the Detroit region. Econ. Geogr. 46 (2), 234–240.
van Kooten, G.C., Johnston, C., 2014. Global impacts of Russian log export restrictions and the Canada–U.S. lumber dispute: modeling trade in logs and lumber. Forest Policy Econ. 39, 54–66.
Xiang, Q., Yin, R., 2006. Impact of globalization and policy change on United States softwood lumber trade. For. Sci. 52 (4), 381–389.
Yin, Z., Wang, F., Gan, J., 2020. Spatial spillover effects of global forest product trade. Forest Policy Econ. 113, 102112.
Zhai, J., Kuusela, O.P., 2022. Incidence of domestic subsidies vs. export taxes: An equilibrium displacement model of log and lumber markets in Oregon. Forest Policy Econ 135, 102647.
Zhang, D., 2001. Welfare impacts of the 1996 U.S.-Canada softwood lumber (trade) agreement. Can. J. For. Res. 31, 1958–1967.
Zhang, D., 2007. The Softwood Lumber War: Politics, Economics and the Long U.S.-Canada Trade Dispute. Resources for the Future Press, Washington, DC.
Zhang, D., Li, Y., 2009. Forest endowment, logging restrictions, and China's timber products trade. China Econ. Rev. 20 (1), 46–53.
Zhang, X., Sun, C., Munn, I.A., Gordon, J., 2021. How to protect the U.S. forest products industry from the perspective of trade? A comparison of policies within the forest supply chain. Forest Policy Econ. 133, 102616.