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What Is the Relationship Between Forest Footprint and Export of Forest Products? Evidence from Method of Moments Quantile Regression

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Abstract: This study investigates the long-run relationship between forest footprint, which shows the amount of forest area needed for pulp, industrial wood, firewood and timber, and forest products as an environmental indicator. Forest footprint, forest product exports, forest product production, forest areas, biomass consumption, and urbanization variables are used in the analyses with annual data for the period 2000–2017 for selected European Union (EU) countries. As a result of the cointegration analyses, there is a long-run relationship between the variables. According to the results of coefficient estimation, it is concluded that forest product exports and urbanization have a decreasing effect on forest ecological footprint, while forest area, forest product production, and biomass consumption have an increasing effect. According to the Method of Moments Quantile Regression (MMQR) estimation results, it is concluded that forest product exports have a decreasing effect on forest footprint in all quantiles in the analysis period. The production of forest products is determined as the variable with the highest negative impact on the forest's ecological footprint. The effect of urbanization is calculated as positive, but it is the variable with the lowest impact together with forest area. Biomass consumption is found to significantly reduce the forest footprint. In view of the aforementioned findings, it is recommended that efforts be made to promote high-value added, sustainable, and environmentally friendly production processes in forest products exports. This is considered to be a key strategy to reducing the ecological footprint of forests.

Keywords: forest footprint; foreign trade; biomass; urbanization; Moments Quantile Regression (MMQR)

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1. Introduction

In global competition, the main objective of developed and developing countries is to ensure stable economic growth. Economic growth should basically be achieved through an increase in production. While the increase in production accelerates with the growth of industrialization and international trade, this situation brings the critical importance of energy resources to the fore. Since countries' economies mainly depend on fossil fuels in production, this creates pressure on natural resources and causes nature to exceed its limits. As a result, economic growth and international trade may have a detrimental effect on ecological balance if precautions are not adopted in the medium and long term. Especially in developed countries, economic growth affects citizens' quality of life and consumption behavior and may lead to environmental problems. These problems are climate change, ozone depletion, destruction of biodiversity, CO_2 emissions, global warming, decrease in forests, and increase in deserts, which have been frequently mentioned recently.

Ignoring environmental problems, accelerated urbanization, and problems caused by high technology create many ecological problems. As a result, environmental scientists have developed different techniques to calculate the efficiency and quantity of natural resources. The concept of ecological footprint, first introduced by [1], can be considered as an important indicator of a sustainable environment and development. They aimed to measure the amount of waste generated as a result of the use of natural resources with an ecological footprint. According to Ref. [2] ecological footprint not only measures the ecological areas required to meet social needs but also takes waste into account. The ecological footprint, calculated in global hectares, measures enough biological area (pastures and grasslands, seas and lakes, edible soil, carbon sequestration areas) required to meet all needs [3,4]. According to Ref. [5], the ecological footprint can be calculated by multiplying consumption area, production area, and population, while according to Ref. [6], the ecological footprint is the sum of consumption, production, and net exports. In other words, in the formation of the ecological footprint, in addition to the products obtained by using the resources within the country, the fact that these products are subject to international trade also emerges as an important factor to be considered.

Sustainability has become an important concept in many disciplines; in particular, the sustainable balance of the environment is of crucial importance from a socio-economic point of view. While foreign trade increases the sustainability capacity of the economy, it can also trigger an environmental problem. The level of development of countries leads to differentiation in the impact of foreign trade on the environment. Developed economies that produce environmentally sensitive systems aim to minimize environmental problems. However, since per capita income is high in developed economies, consumer preferences may also influence the environment negatively. For this reason, the consumption of recyclable products should be encouraged in these countries. It is stated that the driving force in the sustainable development process is green growth [7]. Green growth is a policy that aims to minimize the environmental damage caused by the use of natural resources in economic growth towards climate change and ecological degradation [8]. Economic growth, which is expressed as an increase in the amount of production, also requires the development of international trade. International trade is an important factor in the economic development of countries as a result of globalization. As trade expands, natural resource consumption caters to not only domestic but also foreign demand [9]. The products produced and consumed are obtained by combining both domestic and foreign resources. In other words, with the realization of international trade, the footprint of products is also subject to foreign trade. Therefore, the export of products manufactured using domestic resources also means the export of an ecological footprint.

Ref. [10] suggested that countries can be categorized according to their ecological footprint. The categorization is based on the following criteria: Countries with ecological surpluses exceeding their net biocapacity exports have either stable or increasing ecological capital. In contrast, countries with net biomass exports greater than their ecological surpluses face a decline in ecological capital, even though the consumption of their population requires less biomass than is available. Countries with biomass importers and ecological deficits are already experiencing deteriorating ecological capital. Finally, countries that are both ecological surpluses and net biomass importers have the potential to enhance their ecological capital.

Along with international trade, another factor affecting environmental problems is urbanization. The need for shelter arising with the increase in population stimulates the construction sector. The construction sector is expanding, encroaching on agricultural and forest areas. Therefore, the negativities created by the construction sector and subsequent rapid urbanization increase problems such as deforestation and ecological imbalance. In other words, the rapid increase in urbanization and the growth of the construction sector, it highlights that various strategies and standards should be developed to reduce CO_2 emissions. Therefore, it can be said that the construction sector is one of the sectors that should take an active role in combating environmental problems [11–13].

Fossil fuels are seen as the most important factor that causes environmental pollution caused by urbanization and increases CO_2 emissions. For economies based on fossil fuel consumption, the transition to environmentally sustainable energy sources requires a prolonged struggle. In this process, attention is drawn to renewable energy sources. Biomass energy, which is one of these sources and known as an environmentally friendly source, is expected to reduce environmental problems [14]. Utilizing biomass and biomass-derived biofuels offers both environmental benefits and drawbacks. The fact that biomass and biofuels are substitutes for fossil fuels as energy sources is one advantage. A greenhouse gas called carbon dioxide (CO_2) is released when fossil fuels and biomass are burned. However, biomass is a carbon-neutral energy source because the plants that produce it absorb nearly as much CO_2 during photosynthesis as they emit when burned [15]. Biomass energy consists of organic wastes obtained from agricultural and forestry products, animals, and consumption. The impact of forest products is especially crucial in the development and utilization of biomass energy. In order to eliminate the CO_2 emission problem, biomass energy consumption has increased in many countries in recent years, thus aiming to reduce CO_2 emissions [16]. In 2021, the share of biomass energy consumption in renewable energy consumption in the European Union is 59% and it is one of the most important renewable energy sources [17].

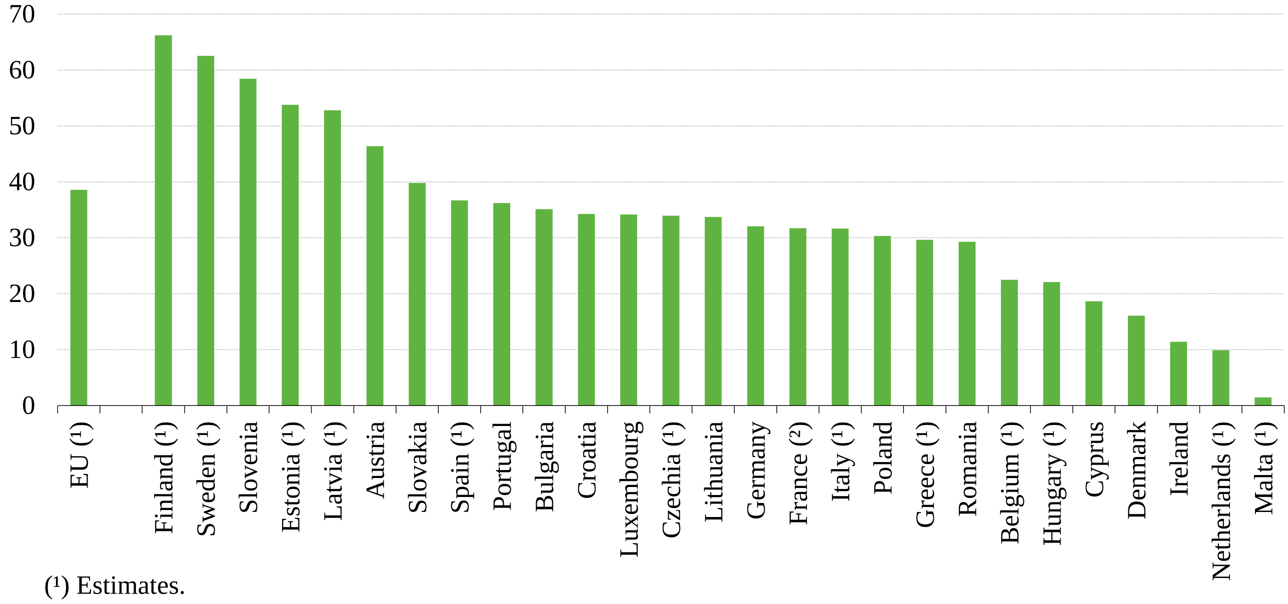
It is known that new technologies as well as the economic development which arose with the Industrial Revolution led to the growth of the urban population density and widening the scope of production and consumption. Global natural resources are limited, and the high rate of urbanization and population growth has led to environmental problems such as the decrease in the forest or agricultural areas, deterioration of ecological balance, and climate change. Increasing primary energy consumption after industrialization increases CO_2 emissions. This situation has been the cause of global warming because of climate change, which is a longstanding problem in the global climate order. It is known by researchers and politicians that climate change poses an urgent threat to sustainable development and the survival of humanity [18,19]. According to Ref. [20], the process of gathering large permanent residents in relatively small areas and the resulting dense metropolises are known as urbanization. Additionally, the movement of people from agricultural to non-agricultural areas is known as urbanization. A significant rise in expenses, social inequalities, and adverse environmental effects is caused by the physical concentration of people in metropolitan regions. Because of the high rate of housing, increased investment, and industry, among other considerations, further urbanization has a significant impact on energy consumption. It is foreseen that deforestation, which is a reduction in forest areas and forest area degradation caused by cutting down trees, is responsible for approximately 12%–15% of the global warming problem caused by climate change [21].

Rapid urban expansion, industrialization without environmental considerations, the burning of fossil fuels, and the introduction of new technologies can result in severe ecological challenges. Researchers focused on addressing these environmental issues have developed various methods to estimate the availability and productivity of natural resources. In Refs. [22–29], the ecological footprint has often been utilized as an environmental indicator. This preference is due to its comprehensive nature, encompassing several sub-components such as the fishing ground footprint, grassland footprint, cropland footprint, built-up land footprint, forest footprint, and carbon footprint. Additionally, the ecological footprint has been less extensively explored compared to other indicators. However, studies focusing on the forest footprint, a sub-component of the ecological footprint, are relatively scarce [12,21,30,31]. Ref. [32] define the forest footprint as the forest area required for producing pulp, industrial wood, firewood, and timber. The Forest Footprint shows the number of square meters of forest that are lost as a result of changing consumption patterns. Several criteria are used in the calculation, and the stages involved are described below. Basically, the concept is to weigh by a deforestation risk ratio, assess the amount of deforestation-risk commodities in a final product, and then determine the surface area required to manufacture this quantity based on the typical production output. The Forest Footprint indicator is therefore provided [33]. An estimate of the amount of carbon dioxide that can be absorbed and cleaned up by the world's forests serves as the foundation for the ecological footprint calculation. The amount of carbon dioxide released into the atmosphere falls if the area of mature forest declines and the area of productive forest increases [34]. Including the forest footprint as an environmental indicator in research could significantly enrich the literature, as it serves as a critical measure for evaluating environmental policies and pollution. For these reasons, our study incorporates the forest footprint as one of the environmental indicators in the analysis.

In this study, the existence of a relationship between forest footprint, as a component of the ecological footprint, and forest product exports and production is examined. In this context, according to FAO data, 49.2% of the world's forest products exports in 2021 were carried out by European Union (EU) countries. The share of 27 European Union countries in world trade was 14.7% in 2021 [35]. For this reason, EU countries, which have an important position in the trade of forest products, constitute the sample of the study. As can be seen in Figure 1, in 2020, 39% of the EU territory accounted for forests. In Finland, Sweden, Slovenia, Estonia, and Latvia, forests account for a significant portion of the national land area, covering 66%, 63%, 58%, 54%, and 53% of the terrestrial territory, respectively.

European Union countries have a critical role in the forest products sector in the world, both in terms of production and consumption. In addition, the Union is a global pioneer in the introduction and implementation of sustainable forest management and circular economy policies. The production of forest products such as softwood timber and wood-based panels has increased in countries such as Germany, Poland and Finland. In addition, European Union countries have a strong position in the international renewable energy market with products such as wood pellets and biofuels. Global shipments of these products not only contribute to the expansion of the market, but also accelerate the transition to a low carbon economy. The EU's environmental standards and regulations, in line with international obligations such as Paris, whose aim is to reduce global warming, are beneficial for environmental and economic sustainability as they promote the responsible use of timber products. These qualities make EU countries a leading region for international timber exchange and the development of new approaches [36,37].

The focus on EU countries contributes to increasing the methodological depth of the study and optimizes the practical application of its results. The existence of common environmental policies and regulations ensures consistency and comparability between these countries. For example, the 2020 Climate and Energy Package (CEP), launched in 2007 and entering into force in 2010, set EU targets for renewable energy, energy efficiency and greenhouse gas (GHG) emission reductions for the period 2010–2017 [38]. Furthermore, the Forest Law Enforcement, Governance and Trade (FLEGT) Action Plan was launched to address the problem of illegal logging by strengthening forest initiatives, promoting sustainable forestry and legal timber trade and facilitating biomass and other renewable sources [39]. The significant involvement of EU countries in the international exchange of forest products and their commitment to implementing strategies for the sustainable management of forests has resulted in the development of management measures with significant global implications. The European Union's initiatives reflect the complexity of policy instruments within the frameworks of the circular economy and renewable energy. Additionally, the EU's focus on specific environmental issues during this period, such as biodiversity and forest protection, makes the research more targeted and practically oriented.



(1) Estimates.
(2) Estimates refering to metropolitan France.

Figure 1. Forest area in the EU, 2020 (%) [40].

Forests are essential for health, welfare, urbanization, and biodiversity and are important in combating climate change. According to the European Union Forest Strategy, forests will contribute to achieving at least a 55% greenhouse gas emission reduction target by 2030. In addition, this strategy aims to achieve climate neutrality, or in other words, net-zero emissions, by 2050 [41]. The goal of this study is to explore the relationship that exists between the forest footprint and the forest product export and production in the countries of the European Union. The authors performed panel data analysis for 22 European Union countries for the period of 2000–2017. This research seeks to extend the area of forestry and environmental and international trade studies and provides innovative policy suggestions to the forest policy and forestry industry of the European Union. The period from 2000 to 2017 represents a limitation in the data availability for the variables included in the model. Moreover, considering this period in the context of developments in the global economy and the cyclical evolution of EU countries, it has facilitated the achievement of robust and meaningful outcomes.

The study distinguishes itself from the existing literature through several innovative contributions and original approaches. The text suggest the environmental forest footprint as a new environmental index and demonstrates an alternative dimension of sustainability measurement metrics. Using this indicator, the research investigates the environmental factors in the context of foreign trade, especially concerning the forest footprint in the trade of forest goods.

A notable aspect of the study is its emphasis on European Union countries, which collectively stand as one of the largest exporters of forest products, accounting for almost half of the global exports. This geographical perspective enhances the economic and environmental importance of these countries and enables a more detailed examination of their particular difficulties and prospects.

In a methodological way, the paper makes use of advanced econometric techniques for carrying out comparison in order to establish the strength and accuracy of the results obtained. In addition, the study provides detailed empirical results by assessing a wide range of data such as export of forest products, production of forest products, area of forests, and the use of biomass from forests.

Cognitively, the study enables EU-22 countries to develop preventive policies that are designed to mitigate potential threats to the environment. The policy recommendations are based on the specific interdisciplinary challenges of the study which combine theoretical constructs to provide a comprehensive framework in which to interpret the findings.

The study is structured to begin with an introduction that outlines the theoretical and conceptual framework. This is followed by a review and discussion of the relevant literature in the next section. The third section presents details on the model, dataset, and methodology derived from the literature, along with an explanation of the findings from the analysis. Finally, the study concludes with recommendations aimed at market participants, policymakers, and future researchers, based on the results obtained from the analyses.

2. Literature Review

In recent years, environmental economics literature has been intensively studied through different methods and models. Most of the studies focus on testing the stationarity of environmental indicators, the Environmental Kuznets Curve (EKC), and the Pollution Paradise Hypothesis (PHH). The main points where environmental economics studies differ from each other are primarily the environmental indicators selected, the models and variables used, and the country samples selected. In that respect, once the papers in the literature are viewed, it is seen that CO_2 emission is predominantly preferred as an environmental indicator, although ecological footprint has started to be used more in recent analyses.

Researchers working on environmental economics and environmental problems develop different techniques to calculate the productivity of nature and the number of natural resources. One of the most significant environmental indicators is the ecological footprint, which was coined by Ref. [1] and is considered an indicator of sustainability and sustainable development. WWF (World Wildlife Fund) and Ref. [32] interpreted the comprehensiveness of ecological footprint under six subheadings as "grassland footprint, fishing ground footprint, agricultural land footprint, forest footprint, built-up area footprint and carbon footprint". In this research, "forest footprint", which is calculated as the amount of forest area needed for industrial wood, pulp, firewood, and timber, is preferred as an environmental indicator for the reasons stated in the introduction.

This analysis seeks to determine the relationship between forest product trade and the forest footprint. In addition to the insufficient number of studies examining the relationship between international trade and the environment, there are not many studies in which forest footprint is preferred as an environmental indicator. For this reason, it is thought that this study, in which the relationship between forest footprint and forest products trade is tested, will fill a big gap in the literature and make great contributions to the forestry sector.

In the literature, Refs. [4,42–49] tested the relationship between the environment and international trade in their studies and mostly used ecological footprint and CO_2 emission variables as environmental indicators. The variables used in the models are environmental and economic indicators such as exports, imports, foreign direct investment, economic growth, trade openness, renewable energy, urbanization, financial development, and energy consumption. Dynamic symmetric and asymmetric panel causality, Dumitrescu-Hurlin causality, FMOLS, GMM, FGLS DOLS, AMG coefficient estimators, ARDL, and Johansen cointegration tests are preferred as methods. When the studies in the literature are analyzed in general, It is observed that international trade has a negative impact on the environment.

When the studies using forest footprint are examined, it is seen that there are interdisciplinary studies in different dimensions, such as Refs. [18,21,50–54]. In these papers, it is observed that field research on the forestry sector and technical and theoretical research have been carried out. It can be said that socio-economic research using forest footprint as an environmental indicator has not worked at an adequate level. For the reasons mentioned, it is thought that testing the relationship between forest footprint and forest products trade with empirical methods in this study will fill a big gap in the literature.

Regarding the related studies examining the relationship between forest footprint and trade in forest products, Ref. [30] work on a new calculation method to assess the forest area footprint of countries. The method of the research includes multi-regional input-output techniques and the calculations of the FAO of the United Nations on the consumption, production, and trade of primary, intermediate and final forestry products. The calculations incorporate data from 223 countries and 20 different forest products. The forest footprint results indicate that 22 million hectares (Mha) of forests were harvested globally in 2014, with 42% of this amount allocated to satisfy international demand for forest products. Ref. [55] examined the EKC hypothesis concerning deforestation in Africa during the period from 1990 to 2016. By employing the panel GMM estimator, the EKC hypothesis is validated for Africa, with the turning point estimated at USD 3000. The analysis concludes that trade in forest products, biomass consumption, agricultural production, population growth, and political freedom are key factors driving net deforestation. Ref. [56] conducted analyses on OECD and non-OECD countries in Africa, Asia, and Latin America between 1990 and 2007. They analyze how factors like economic growth, agricultural land conversion, population, urbanization, trade, and grain yield affect deforestation rates using the GMM method within the framework of the EKC hypothesis. The findings reveal that the N-shaped EKC hypothesis holds for OECD countries, while the inverted U-shaped EKC hypothesis applies to the African region. The study concludes that population growth contributes to increased deforestation, particularly through the conversion of agricultural land. The analyses indicate that increased international trade and urbanization affect regions in different ways. Ref. [57] applied the ecological footprint model to assess the impact of forest footprint on China's forest product imports from 1995 to 2007. Their findings indicate that forest product imports do not significantly threaten global forest resources in terms of ecological footprint.

A review of the studies on forest footprint and the forestry sector reveals that the main differentiation lies in the methodology used, the variables preferred for the model, and the country or country group samples selected. It is also noted that the studies do not directly analyze the relationship between forest footprint and trade in forest products but rather interpret the results with the analyses performed within the scope of the EKC hypothesis. In this regard, it is commonly accepted that there is a connection between the trade in forest products and the forest footprint. Apart from the reasons for the contribution of the study to the literature, it is thought that the variables "forest footprint, forest product exports, forest product production, forest areas, biomass consumption, and urbanization" used in the established model will bring innovation to the literature. The study's selection of the country sample also adds significantly to the body of literature. It is thought that the selection of 22 EU countries in the analyses and the policy recommendations made based on the findings obtained will make significant contributions to both the literature and the administration of the relevant EU countries in terms of environmental policies. Finally, a distinguishing feature of this study compared to the existing literature is the empirical method chosen. After testing the long-run relationship between the variables by using new generation panel data analysis techniques in the analyses, comparisons and propositions were made between the coefficient estimators FMOLS, DOLS, AMG and Quantile regression analysis results.

3. Econometric Analysis

As part of the study's analysis, within the scope of the relationship between the environment and foreign trade, the long-run relationship between forest footprint and exports of forest products and the effect of exports of forest products on forest footprint are tested. The main hypothesis of the study is constructed as "There is a long-run relationship between forest footprint and exports of forest products and exports of forest products have an impact on forest footprint". The hypothesis is tested by using new generation panel data analysis techniques on EU countries with annual data for the period 2000–2017. Due to the data limitations associated with the variables used in the model, data from 22 EU countries (Austria, Belgium, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Italy, Lithuania, Latvia, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden) are used in the analyses. The main reason for selecting EU countries as the sample is that according to FAO data, they make up 49.2% of the world's forest products exports as of 2021. In addition, the size of the forest areas owned by the EU countries was also effective in the selection of this country group.

3.1. Dataset and Model

The test of the hypothesis is analyzed through the following model. The variables in the models are selected based on existing literature and in accordance with the hypothesis established in this study. In this context, the forest footprint variable (FEFP), which represents forestry in the literature, is included in the model as the dependent variable. As independent variables, forest product exports (LFEXP), forest product production (LFPRO), and forest areas (FAREA) are determined. In addition, biomass consumption (LBIO) and urbanization (URBAN) variables, which are known to be effective in the dependent variable forest footprint, are added to the model as control variables. Descriptive information of the variables is provided in Table 1. The databases from which the data are obtained are reliable institutions and the variables listed above are generally analyzed with the information obtained from these databases. Therefore, there is no problem in terms of data reliability.

Table 1. Variable Explanations.

Variable	Explanation	Source
FEFP	Forest Products Footprint (gha per person)	[58]
LFEXP	Forest Product (Forestry) Export (USD)	[59]
LFPRO	Forest Product Production (USD)	[59]
FAREA	Forest area (% of land area)	[60]
LBIO	Biomass Consumption	[61]
URBAN	Urban population (% of total population)	[62]

In the paper exploring the relationship between forest footprint and exports of forest products, the model formulated within the specified sample and data range is developed as follows, in line with the established hypothesis.

$$FEFP_{it} = \beta_{it} + \beta_1 LFEXP_{it} + \beta_2 LFPRO_{it} + \beta_3 FAREA_{it} + \beta_4 LBIO_{it} + \beta_5 URBAN_{it} + \varepsilon_{it} \quad (1)$$

In the model, $t = 1, 2, 3, \ldots, T$ denotes time dimension, $i = 1, 2, 3, \ldots, N$ denotes cross-section data, and ε denotes error term. LFEXP, LFPRO and LBIO variables in the model are logarithmic and included in the analyses. The reason for the logarithmic transformation is to minimize the variables by logarithmising to a given base and to facilitate the interpretation of the results of the analysis. Other variables (FEFP, FAREA, URBAN) are included in the analyses without being logarithmically transformed. In addition, there is no deficiency in the observation values of the variables. Therefore, balanced panel data analysis is performed in this paper.

3.2. Econometric Method

A structured methodological sequence was followed in a study conducted to examine the relationship between forest product exports and forest footprint from 2000 to 2017.

Firstly, descriptive statistics for the model's variables were calculated and interpreted. Secondly, CD test developed by Ref. [63] was applied to examine potential cross-sectional dependence among the variables. Thirdly, the Delta test, developed by Ref. [64], was used to assess whether the slope coefficients are homogeneous or heterogeneous. Fourthly, the CADF (Cross-sectional Augmented Dickey Fuller) unit root test, introduced by Ref. [65], was conducted to check for unit roots in the variables. Fifthly, LM bootstrap cointegration test developed by Ref. [66] was performed to investigate the long-term relationships between the variables. Finally, Moments of Methods Quantile Regression (MMQR) analysis and several estimators, including DOLS (Dynamic OLS), FMOLS (Fully Modified OLS), and AMG (Augmented Mean Group), were employed to estimate the coefficients of the long-run relationships.

3.3. Descriptive Statistics of the Variables

In econometric studies, it is important to present and interpret the descriptive statistics of the variables included in the model before conducting further analyses. This allows for a clear understanding of the changes in the variables over the specified years and provides insights into their statistical variations. The descriptive statistics for the variables used in the analysis are presented in detail in Table 2.

Table 2. Descriptive statistics.

Variables	FEFP	LFEXP	LFPRO	FAREA	LBIO	URBAN
Mean	0.845	6.267	7.236	38.038	7.571	71.551
Maximum	3.889	7.370	8.213	73.736	8.537	97.961
Minimum	0.000	4.844	6.016	10.649	6.304	50.754
Std. Dev.	0.656	0.591	0.520	15.607	0.548	12.787
Skewness	1.972	−0.163	−0.063	0.679	−0.220	0.130
Kurtosis	6.976	2.179	2.328	2.979	2.473	2.012
Jarque-Bera	517.484	12.886	7.706	30.446	7.770	17.215
Probability	0.000	0.002	0.021	0.000	0.021	0.000
Observations	396	396	396	396	396	396

According to Table 2, which includes descriptive statistics, it is determined that FEFP, FAREA and URBAN variables follow a right-skewed distribution, while LFEXP, LFPRO and LBIO variables follow a left-skewed distribution. The results of the Jarque-Bera test, applied to assess the normality of the variables' distribution, indicate that the variables do not follow a normal distribution. This suggests that coefficient estimates obtained using OLS will yield inconsistent results. Therefore, it is decided that coefficient estimation with quantile regression would yield consistent and robust results.

3.4. Cross-Sectional Dependency Test

The growing interdependence of countries in the world economy means that positive or negative developments, as well as crises, in one country can affect others because of their integration. This is an inevitable consequence of globalization. Therefore, econometric studies need to conduct cross-sectional dependence tests to assess the interactions between countries and measure how a shock in one country can affect others. In the study, the relationship between forest product exports and forest footprint is analyzed across selected EU countries, where N = 22 and T = 18. Given that N > T, the analyses use CDlm test, with the results presented in Table 3 [67].

Table 3. Cross-sectional dependency test results.

	FEFP	LFEXP	LFPRO	FAREA	LBIO	URBAN	Model
CD_{lm} Test Statistic	2.241 [b]	50.444 [a]	15.493 [a]	40.117 [a]	6.428 [a]	16.910 [a]	5.066 [a]
Prob.	0.025	0.000	0.000	0.000	0.000	0.000	0.000

Note: a and b indicate that there is cross-sectional dependency at 1% and 5% significance level, respectively.

Upon analyzing Table 3, which presents the results of the cross-sectional dependency test, it is observed that the probability values for all variables are significant. As a result, based on the CDlm test, the null hypothesis—"there is no cross-sectional dependency"—is rejected, and the alternative hypothesis—"there is a cross-sectional dependency between countries in the panel data"—is accepted. This finding aligns with the dynamics of today's globalized world, suggesting that a shock to one of the selected EU countries will also impact other countries.

3.5. Panel Unit Root Test

When examining the relationship between forest product exports and forest footprint, second-generation unit root tests should be employed due to the cross-sectional dependence among the variables in the model. In this study, the CADF unit root test developed by [65] is used, as it is widely recognized in the literature. The key differences of the CADF test compared to other stationarity tests are as follows. It delivers consistent results when the number of cross-sectional units (N) exceeds the time period (T), taking into account both the countries and the time dimension. The test statistic is calculated for each unit in the panel, and the CIPS (Cross-Sectionally Augmented IPS) statistic is derived by averaging the individual test statistics. Additionally, the CADF test extends the ADF regression by incorporating lagged cross-sectional averages [65].

The findings presented in Table 4, derived from the CIPS panel unit root test, indicate that all variables are characterized by a unit root at their level values. This observation indicates that a shock to one of the countries incorporated within the model generates persistent effects, which do not dissipate immediately. Moreover, the non-stationarity of the series is a necessary condition for performing cointegration tests. It is concluded that when the same test is conducted by subtracting the first order of all series in order to induce stationarity of the series, the variables acquire stationarity at I(I) level. Subsequently, it has been determined that the variables are integrated to a first order level.

Table 4. Unit Root Test Results.

Variables	CIPS Statistics	
	Level	First Difference
FEFP	−1.580	−2.771 [a]
LFEXP	−1.607	−2.792 [a]
LFPRO	−1.500	−2.629 [a]
FAREA	−1.253	−2.464 [a]
LBIO	−1.288	−2.956 [a]
URBAN	−1.441	−2.562 [a]

Note: Table critical values for 1%, 5%, and 10% significance levels are −2.57, −2.21, and −2.10, respectively. a indicate significance level at 1%.

3.6. Homogeneity Test

When analyzing panel data, it is important to check that all nations have consistent long-run cointegration relationship coefficients for the variables being studied. The homogeneity test is used to determine whether changes in one nation have the same impact on other nations. The coefficients in models built for nations with various economic structures are anticipated to be heterogeneous, whereas the coefficients in models built for nations with comparable economic structures are anticipated to be homogenous. In this study, Ref. [64]'s Slope Homogeneity Test (Delta test) is employed to assess homogeneity. While the Delta test is suitable for large samples, the Delta adj. test is more appropriate for smaller ones. The results are presented in Table 5.

Table 5. Homogeneity test results.

	Test Statistics	Probability Value
$\hat{\Delta}$ Delta_tilde	6.827 [a]	0.000
$\hat{\Delta}_{adj}$ Delta_tilde_adj	8.591 [a]	0.000

Note: a indicate that the slope coefficients are heterogeneous at 1% significance levels.

According to the Delta test results, the slope coefficients vary across units in the long run because the probability value of both test statistics is less than 0.05. In other words, it is determined that the variables are heterogeneous at the 1% significance level.

3.7. Panel Cointegration Test Results

The panel cointegration tests developed by Ref. [66] are used to analyze the long-term relationship between the variables in the model. What distinguishes this test from previous panel cointegration tests is that it is based on the Lagrange Multiplier (LM) test introduced by [68]. With the estimation of regression model 2's Fully Modified Ordinary Least Squares (FMOLS), y_{it} is first calculated from the error terms (zit).

$$y_{it} = \alpha_i + x'_{it}\beta_i + z_{it}\ ;\ z_{it} = u_{it} + v_{it} \quad (2)$$

In the second stage of the test, the *LM* statistic is calculated using the test in the following equation.

$$LM_n = \frac{1}{NT^2}\sum_{i=1}^{N}\sum_{t=1}^{T} w^2{}_i\, s_{it}^{-2} \quad (3)$$

In the *LM* statistic calculated in Equation (3), the partial sum process of the residuals obtained from estimation 2, i.e., z_{it}, $w_i{}^2$, denotes the long-run variance of u_{it} conditional on Δx_{it}. The null hypothesis of the test is "cointegration exists for all cross-sections" and the alternative hypothesis is "cointegration does not exist for some cross-sections" [66]. The calculated test statistic shows a standard normal right tail distribution. However, if there is a cross-sectional dependency problem in the panel, the standard normal distribution cannot be used. Nevertheless, in data sets with cross-sectional dependency, Ref. [66] suggest the use of critical values obtained from the "bootstrap" method within the framework of the Sieve approach. They used bootstrap techniques to consider the cross-sectional dependence between the series in the analyses and to improve the test performance. The test is generally accepted since it considers the cross-section dependence and gives good results for small samples [66]. The results can be seen in Table 6.

Table 6. Cointegration test results.

LM Test Statistic	5.268
Bootstrap *p*-value	0.964

Note: The number of bootstrap cycles is 1000 and the lag length k is taken as 4.

The cointegration analysis results shown in Table 6 reveal that there is a long-run relationship between forest footprint and forest product exports, forest product production, forest area, biomass consumption and urbanization. These findings have important implications for the understanding of the forest sector's complex interactions with economic, environmental and social dynamics. It is recognized that the export and production of forest products have a significant impact on the forest footprint as economic activities based on the utilization of natural resources. Moreover, an increase in the consumption of biomass has the potential to affect forest areas due to rising demand for energy and industrial activities. Similarly, the process of urbanization has a variety of influences on the forest footprint, as natural areas are replaced by structural developments. The cointegration relationship obtained emphasizes that sustainable management and conservation of forest areas should be considered in an integrated way with economic activities and environmental indicators. In this context, the analysis of selected European Union countries based on data for the period 2000–2017 demonstrates the necessity for the implementation of sustainable policies in order to support the forestry sector.

Also, it is determined that the series move together in the long run and therefore there is no spurious regression problem. Accordingly, in the next stage of the study, the long run cointegration coefficients will be estimated. DOLS and FMOLS methods, which are primarily used for long-run coefficient estimation, provide robust and efficient results by considering the endogeneity and autocorrelation problems. In order to apply DOLS and FMOLS methods, the variables should be stationary at the first order and there should be a cointegration relationship between the series in the model [69,70]. Additionally, the panel AMG method is applied to estimate the coefficients of the independent variables. In this method, cross-section dependence and heterogeneity of slope coefficients can also be taken into account. The method can also be used in the case of the endogeneity problem [71]. The results of DOLS, FMOLS, and AMG tests used for coefficient estimation are given in Table 7.

Table 7. Coefficient estimation results (FMOLS, DOLS and AMG).

Variables	**FMOLS**		**DOLS**		**AMG**	
	Coef.	**Prob.**	**Coef.**	**Prob.**	**Coef.**	**Prob.**
LFEXP	-0.421^{a}	0.000	-0.464^{c}	0.000	-0.954^{a}	0.053
LFPRO	1.376^{a}	0.000	1.273^{a}	0.000	1.762^{a}	0.001
FAREA	0.243^{a}	0.150	0.162	0.004	0.496	0.342
LBIO	2.459^{a}	0.000	2.548^{a}	0.000	2.673^{a}	0.004
URBAN	-0.106^{a}	0.426	0.342	0.002	−0.078	0.240

Note: a and c indicate that the coefficients are statistically significant at 1% and 10% significance levels, respectively.

In Table 7, where the coefficient estimation results are presented, it is determined that the LFEXP variable representing the export of forest products has statistically significant and negative effects on forest footprint according to all three estimation results. The estimation with the highest strength of the effect is constructed with DOLS. The variable LFPRO, which represents the production of forest products, has statistically significant and positive effects on forest footprint according to all three tests. This result is in line with environmental economics theory and expectations. The FAREA variable, denoting the proportion of forest area, has been demonstrated to produce statistically significant effects on the forest footprint, yet this is only observed when employing the FMOLS method. It is also among the findings that the LBIO variable representing biomass consumption has strong and positive effects on the dependent variable in all methods on forest footprint. Finally, the URBAN variable representing the urbanization rate has statistically significant effects on forest footprint only according to the FMOLS estimator.

3.8. Methods of Moments Quantile Regression (MMQR) Results

Quantile regression analysis is a statistical method used to estimate coefficients for all quantiles by establishing a relationship between the explanatory variables and the dependent variable's conditional quantiles. It is a more efficient method compared to other estimation methods, particularly when variables are not normally distributed. The technique was first introduced by Ref. [72]. Quantile regression is a type of weighted regression, where the data points are given different weights depending on whether they are above or below the line of best fit [73]. It can thus be concluded that the panel quantile analysis method provides more flexible, robust and comprehensive results than traditional panel data analysis methods, particularly in cases where the dataset features skewed distributions or outliers. This technique is a valuable tool for researchers, as it facilitates the analysis of heterogeneous effects and the reduction in outliers. The method can be mathematically represented as follows:

$$y_i = x_i b_{\theta i} + \mu_{\theta i}, \quad 0 < \theta < 1 \tag{4}$$

$$Quant_{i\theta}(y_i/x_i) = x_i \beta_\theta$$

In Equation (4), x is the vector of explanatory variables and y represents the dependent variable. μ is the residual vector. $Quant_{i\theta}(y_i/x_i)$ is the quantile value of the identified variable. β_θ is the θth quantile regression [73–75]. Ref. [76] developed the MMQR method and investigated the ways (conditions) to estimate conditional instruments and predict quantiles. They developed an estimator for conditional quantiles by combining estimates of location and scale functions, determined through appropriately defined conditional expectations. The advantage of this method is that it enables the use of techniques suitable for estimating conditional means, such as differentiating individual effects. The model estimating the conditional quantiles of variable Y is as follows:

$$Y_{it} = \propto + X'\beta + \sigma(\delta + Z'\gamma)U \tag{5}$$

In Equation (5), $(\alpha,\ \beta', \delta,\ \gamma')$ are unknown parameters. Z is a differentiable vector k of known transformations of the components of X:

$$Z_l = Z_l(X), l = 1, \ldots k$$

Given $\left\{\left(Y_{it}, X_{it}'\right)'\right\}$ in a panel with n unit and t time period, the estimation of the conditional quantiles of $Q_y(X)$ for a location-scale model is as follows:

$$Y_{it} = \propto_i + X_{it}{}'\beta + \left(\delta_i + Z_{it}{}'\gamma\right)U_{it} \tag{6}$$

In Equation (6), $Pr\{\delta_i + Z_{it}{}'\gamma > 0\} = 1$ and the parameters $(\propto_i, \delta_i)$ give individual i fixed effects. X_{it} is exogenous and iid (independently and identically distributed) for any constant i. U_{it} is iid across units and time. It is also statistically independent of X_{it} and normalized to satisfy the moment condition in the method. Based on this information, Equation (7) can be represented as follows:

$$Q_y(X) = (\propto_i + \delta_i q(\tau)) + X_{it}{}'\beta + Z_{it}{}'\gamma(\tau) \tag{7}$$

In Equation (7), the scalar coefficient $(\propto_i + \delta_i q(\tau)$ represents the quantile-τ fixed effect for individual i or the distributional effect at τ. The distributional effect differs from the fixed effect in that it is not a location shift in general. In other words, it shows the effect of time-invariant individual characteristics. $\int_0^1 q(\tau)d\tau$ implies that $\propto_i$ can be expressed as the average effect for individual i. Accordingly, the τth sample quantile is calculated by solving the following optimization problem:

$$min\sum_i \sum_i \rho_\tau\left(\hat{R}_{it} - \left(\hat{\delta}_i + Z_{it}{}'\gamma\right)q\right) \tag{8}$$

In Equation (8), $\rho_\tau(A) = (\tau - 1)AI\{A \le 0\} + \tau AI\{A > 0\}$ is a control function [76]. Consequently, the MMQR method has been demonstrated to be more robust than traditional approaches, as it considers the full distribution (conditional quantiles) of the dependent variable. Moreover, this approach has been demonstrated to be especially effective in modelling individual effects and producing efficient results even in cases where variables are not normally distributed.

The MMQR estimation results, which provide a more detailed analysis according to the values of the dependent variable, are displayed in Table 8.

Table 8. MMQR results.

Variables	Location	Scale	Quantiles 0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
LFEXP	−0.818 [a] (0.000)	−0.172 [a] (0.020)	−0.568 [a] (0.000)	−0.643 [a] (0.000)	−0.707 [a] (0.000)	−0.760 [a] (0.000)	−0.816 [a] (0.000)	−0.875 [a] (0.000)	−0.927 [a] (0.000)	−1.011 [a] (0.000)	−1.204 [a] (0.000)
LFPRO	2.083 [a] (0.000)	0.396 [a] (0.006)	1.150 [a] (0.000)	1.683 [a] (0.000)	1.829 [a] (0.000)	1.951 [a] (0.000)	2.079 [a] (0.000)	2.216 [a] (0.000)	2.334 [a] (0.000)	2.527 [a] (0.000)	2.969 [a] (0.000)
FAREA	−0.020 [a] (0.000)	0.001 (0.926)	−0.020 [a] (0.000)	−0.020 [a] (0.000)	−0.020 [a] (0.000)	−0.020 [a] (0.000)	−0.020 [a] (0.000)	−0.020 [a] (0.000)	−0.020 [a] (0.000)	−0.020 [a] (0.000)	−0.019 [b] (0.026)
LBIO	−1.716 [a] (0.000)	−0.384 [a] (0.000)	−1.159 [a] (0.000)	−1.328 [a] (0.000)	−1.469 [a] (0.000)	−1.587 [a] (0.000)	−1.712 [a] (0.000)	−1.844 [a] (0.000)	−1.959 [a] (0.000)	−2.146 [a] (0.000)	−2.575 [a] (0.000)
URBAN	0.018 [a] (0.000)	0.005 [a] (0.004)	0.010 [a] (0.000)	0.013 [a] (0.000)	0.015 [a] (0.000)	0.016 [a] (0.000)	0.018 [a] (0.000)	0.020 [a] (0.000)	0.022 [a] (0.000)	0.024 [a] (0.000)	0.030 [a] (0.000)
Constant	3.345 [a] (0.000)	1.013 [b] (0.011)	1.875 [a] (0.000)	2.321 [a] (0.000)	2.694 [a] (0.000)	3.005 [a] (0.000)	3.334 [a] (0.000)	3.683 [a] (0.000)	3.987 [a] (0.000)	4.479 [a] (0.000)	5.611 [a] (0.000)

Note: a and b indicate significant levels at 1% and 5% respectively. Values in parentheses indicate probability.

Upon thorough examination of the findings, it is evident that the impact of the LFEX variable on EFP is statistically significant and negative, as observed in other estimation methods. Moreover, in countries where the FEFP variable is elevated, the effect of the LFEX variable is also pronounced. These results reveal that the increase in exports of forest products accelerates the decrease in environmental pollution (forest footprint) in countries with higher forest footprint. Similar to other estimation methods, the effect of the increase in the LFPRO variable on the dependent variable was found to be statistically significant and positive. In addition, it is determined that the strength of the effect increases as the value of the FEFP variable increases. In short, in countries with higher forest footprint, the increase in forest product production accelerates the increase in environmental pollution (forest footprint). According to the results regarding the effect of the FAREA variable, a significant and negative effect was observed in all quantiles. Accordingly, it has been determined that low or high values of the FEFP variable do not change the effect of the FAREA variable. It was also concluded that the LBIO variable has a strong effect on the dependent variable like the LFPRO variable. It is also among the findings that the strength of the effect increases as the quantile values increase. These results show that the increase in biomass consumption in countries with higher forest footprint reduces environmental pollution faster. Finally, the increase in the URBAN variable is found to have positive and significant effects on the dependent variable. Although the strength of the effect is low, it is determined that the effect increases as the value of the dependent variable increases. According to these results, as the forest footprint increases, the increase in the rate of urbanization increases environmental pollution faster. The visual representation of the results obtained from all estimators is presented in Figure 2.

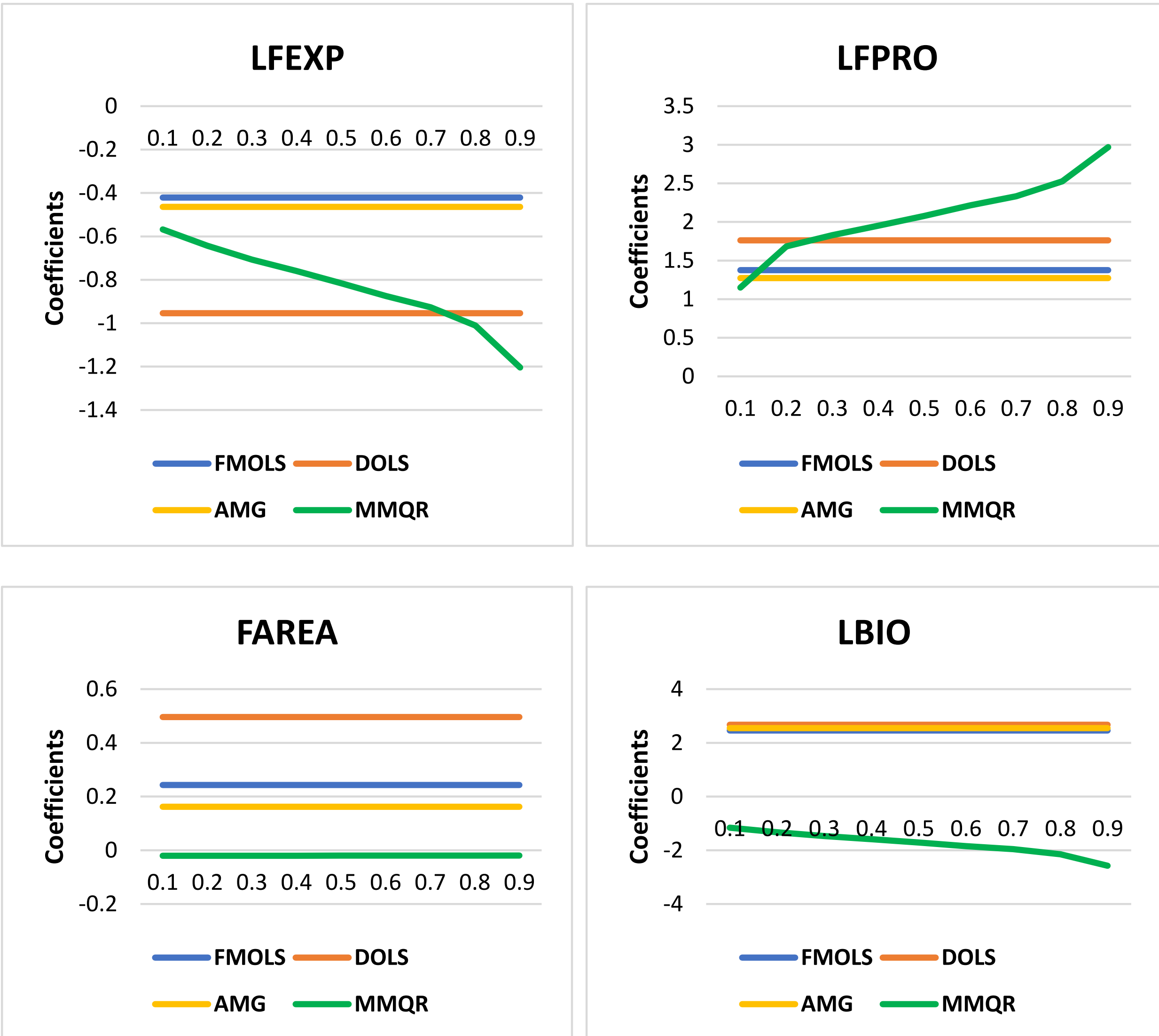


Figure 2. *Cont.*

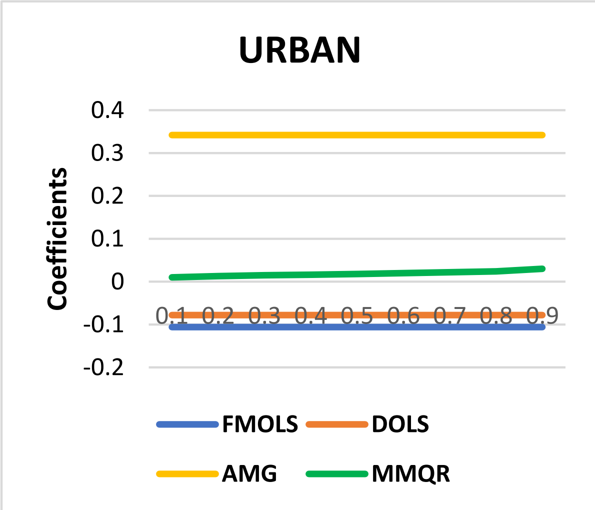


Figure 2. Coefficients obtained from forecasters for all cantiles.

4. Discussion

Forest footprint problems are generally caused by wrong policies regarding basic processes such as production, consumption, and trade. In this context, forest awareness must be firmly established both in producers and consumers as well as decision-makers. Otherwise, there is a risk of many disasters, such as deforestation and forest degradation, that threaten the world's forests. It is crucial to develop new and comprehensive research on these forest footprint problems that require global struggle policies and to increase international cooperation.

Recently, the concept of sustainability has started to increase its importance in many areas. The total forest area of the EU is approximately 182 million hectares, and this area covers approximately 43% of the EU's surface area. Ensuring the sustainability of forest areas, which account for approximately half of the EU's land area, is vital for building a healthy and sustainable future for the EU. The forest footprint is a way of measuring the amount of land and resources needed to manage and utilize forests sustainably. Determining the factors affecting the forest footprint together with the direction of the impact will provide important contributions to policy makers for the development of sustainable policies. Significant changes have been observed in deforestation practices within EU countries. The European Parliament (EP) has approved a one-year postponement of the implementation of new regulations aimed at preventing the import of various products into the European Union (EU), such as soy, beef, palm oil, timber, cocoa, and coffee, that are produced through activities causing harm to forested areas. This decision represents a critical strategic move within EU policies. It is evident that the EU has not adopted a specific policy framework to address the challenges posed by urbanization. For instance, the EU Constitution contains no explicit provisions regarding urban policy. Urban and regional planning is only briefly mentioned in Section 5, which focuses on environmental issues, as part of the areas where framework legislation may be introduced at the Union level.

In the analysis section of the study, the cross-sectional dependence among the variables is initially assessed. The results of CDlm test indicate the presence of cross-sectional dependency. As a result, the CIPS (Cross Sectionally Augmented IPS) unit root testis employed as part of second-generation stationarity tests. The findings reveal that while the variables are non-stationary at that level, they become stationary at the I(1) level after the first differences are taken. This suggests that policy shocks to forest footprint will help reduce environmental pollution in the medium and long term. In other words, if policies addressing environmental issues are expanded and implemented to increase the value-added and exports of forest products in EU countries, greater economic and social benefits can be derived from forest products. The results of the Delta testindicate that the slope coefficients vary across units in the long run, meaning the slope coefficients of the variables in the model are heterogeneous. Finally, LM bootstrap cointegration test is conducted to test for a long-run relationship between the variables, and the results confirm the existence of cointegration. This suggests that the series move together in the long run. Following the identification of a cointegration relationship, the cointegration coefficients and the significance of the variables in the model are tested and interpreted.

According to the results of FMOLS, DOLS, and AMG tests used for coefficient estimation, it is concluded that forest product exports and urbanization have a decreasing effect on forest ecological footprint, while forest area, forest product production, and biomass have an increasing effect. Since the variables are not normally distributed, Quantile Regression Analysis is used to estimate the coefficients of the independent variables. According to the MMQR estimation results, it is concluded that forest product exports have a decreasing effect on forest footprint in all quantiles in the analysis period. The production of forest products is determined as the variable with the highest negative impact on the forest ecological footprint. The effect of urbanization is calculated as positive, but this effect is the variable with the lowest effect together with forest area. Biomass consumption is found to significantly reduce the forest footprint.

When we tried to compare the findings of the analyses with those in the literature, it was not possible to make this comparison due to the lack of similar studies. Nevertheless, we can compare it with some studies that are similar to ours. Studies examining the relationship between forest footprint, which is determined as an environmental indicator, and exports of forest products are limited. The findings obtained in the study are consistent with the Refs. [4,42–49], which examine the relationship between environment and foreign trade. When a comparison is made over the studies based on forest footprint as an environmental indicator, it is compatible with the studies of Refs. [30,55,56] but contradicts the study of Ref. [57]. The main reason for this contradiction is thought to be attributable to the differences in the selected model, method, variables used and country sample.

When evaluating our study in this context, it is believed that it will make a significant contribution to the literature by addressing the economic and socioeconomic dimensions of the forest footprint as an environmental indicator. The model used in the analyses, the chosen methodology, the country sample, and the selected variables all emphasize the uniqueness and originality of the study.

5. Conclusions

Forest footprint issues such as deforestation and forest degradation have been among intensely sensitized problems, especially in developed economies, in recent years. While these forest-related problems may have social costs, their economic costs are also significant. Therefore, decision-makers should base their decisions on forest footprint issues, the associated costs, sustainable forest management, and competitive policies when determining macroeconomic policies to be implemented.

The use of forest resources in the production of developed and developing economies is putting pressure on natural ecosystems and pushing them beyond their limits. Production practices that disregard forest footprint concerns, rapid urbanization, and the negative impacts of advanced technology contribute to various ecological problems. In this context, by conducting analyses on forest footprint and forest product exports, which are selected as indicators in this paper, new policy proposals can be put forth to policymakers governing countries, market players operating in the forestry sector, and researchers interested in this field.

It is important for policymakers to promote sustainable forestry practices and ensure that forest exports are managed in an environmentally and socially responsible manner to reduce the negative impacts of forest product exports on forest footprint. In the group of countries studied, all countries except Croatia, Romania, Greece and Lithuania have national certification systems approved by The Programme for the Endorsement of Forest Certification (PEFC). If forests are managed sustainably, i.e., harvested in a way that allows them to regenerate and maintain their ecological functions and services, forestry exports can contribute to the conservation and enhancement of forest ecosystems.

In the analysis, it was determined that the production of forest products increases the forest footprint. Unsustainable forest production practices may have negative impacts on forest footprint. In order to eliminate the harmful effects of forest product production on forest footprint, policies such as supporting sustainable forest management, responsible resource use, combating illegal logging, reducing waste and promoting alternative materials should be implemented. The production process of forest products can be controlled by practices such as forest certification. The EU should encourage the certification practice carried out by the Forest Stewardship Council (FSC) to the member countries of the Union, and such certification practices should be generalized in the member countries of the Union.

The effect of the urbanization variable included in the model is calculated as positive; however, this effect, along with forest area, is determined to have the lowest impact. In general, managing the impact of urbanization on forest footprint requires a holistic approach that takes into account the social, economic, and environmental dimensions of sustainable urban development. The movement of population from rural to urban areas increases the demand for land, housing, and infrastructure. As forests are cleared to make way for urban development, this can lead to deforestation and land use change. Sustainable land use planning can help balance urban development needs with the need to protect forests and other natural resources. Policies that promote sustainable land use planning, such as zoning regulations and land use planning frameworks, can help to ensure that urban development is carried out in an environmentally and socially responsible manner.

Finally, in the analysis, it is found that biomass consumption significantly reduces the forest footprint. Biomass consumption, when carried out sustainably and responsibly, can help reduce the ecological footprint of forests. In many developed countries, biomass energy is currently recognized as renewable; therefore, subsidies and incentives are in place. In this context, the EU's new 2030 forest strategy aims to advance the forest-based bioeconomy within the limits of sustainability.

In general, promoting sustainable forest management, responsible resource use, combating illegal logging, reducing waste, and promoting alternative materials are necessary steps to reduce the harmful effects of forest output on the forest footprint.

It is recommended that researchers working within the framework of the identified theme first develop new models using different variables across different countries or groups of countries and develop policy recommendations using new generation methods. For researchers who want to examine the relationship between the environment and foreign trade, analyzing the sectoral foreign trade relationship through different environmental indicators will provide important contributions to the literature.

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