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The Role of Institutional and Innovation Ecosystem in Moderating the Impact of Green Practices on Export Performance: Evidence from European Countries

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Abstract

As global merchandise exports reached $22 trillion in 2023 and environmental standards have become increasingly stringent, understanding how green practices influence export competitiveness has become critically important. Although existing research documents positive associations between environmental practices and trade outcomes, the conditions that enhance or constrain these relationships remain underexplored, particularly at the macro level across different export performance segments. Using panel data from 30 European countries for the period 2012–2022, this study examines how institutional and innovation ecosystem factors moderate the relationship between green practices and export performance. Employing panel quantile regression alongside conventional panel methods, we investigate whether regulatory quality, research and development expenditure, and financial market development influence the export benefits derived from ISO14001 certification and environmental patents. Our baseline findings reveal that both environmental management systems and green innovations show positive associations with exports, with ISO14001 certification demonstrating stronger effects in countries with lower export volumes. Notably, regulatory quality and financial market development significantly amplify the export benefits of environmental management systems. However, robustness checks employing instrumental variable estimation and System GMM to address potential endogeneity reveal that these direct effects weaken substantially when reverse causality is explicitly addressed, though point estimates remain consistently positive. These results suggest that while positive associations between environmental practices and export performance appear robust across multiple specifications, establishing definitive causal effects requires cautious interpretation and future quasi-experimental research. The findings highlight the importance of coordinated policy approaches integrating environmental, financial market, and regulatory dimensions, while underscoring that institutional moderators may provide more robust insights than direct effect estimates for understanding how environmental practices enhance competitiveness in international markets.

Keywords: environmental certification; green innovation; regulatory quality; financial market development; panel quantile regression

Academic Editor: Jungho Baek

Received: 14 August 2025
Revised: 10 October 2025
Accepted: 14 October 2025
Published: 15 October 2025

Citation: Khiewngamdee, C.; Chanaim, S. The Role of Institutional and Innovation Ecosystem in Moderating the Impact of Green Practices on Export Performance: Evidence from European Countries. *Sustainability* **2025**, *17*, 9146. https://doi.org/10.3390/su17209146

1. Introduction

In today's globalized economy, export competitiveness remains a critical driver of national economic development and prosperity. As global merchandise exports reached

$22 trillion in 2023 and environmental standards have become increasingly stringent across markets, the relationship between green practices and trade performance has gained unprecedented relevance. As international trade patterns evolve, countries and firms continually seek sustainable sources of competitive advantage in global markets. Concurrently, mounting environmental concerns have transformed the international trade landscape, with green practices increasingly serving as both regulatory requirements and strategic differentiators [1,2]. This intersection between environmental sustainability and export performance represents a vital yet complex domain meriting thorough investigation, particularly as economies worldwide navigate the transition toward more sustainable development models.

Green practices, ranging from environmental management systems to technological innovations addressing ecological challenges, have emerged as potentially powerful drivers of export competitiveness. These practices enable firms and countries to meet increasingly stringent environmental standards in destination markets, reduce operational costs through resource efficiency, and differentiate products based on environmental attributes [3,4]. Environmental management systems, exemplified by ISO14001 [5] certification, provide formalized frameworks for identifying, monitoring, and mitigating environmental impacts throughout the value chain. Complementarily, green innovations (as reflected in environmental patents) represent technological solutions that can simultaneously address environmental challenges while enhancing productivity [6,7]. These dynamics can be understood through the lens of both institutional theory, which emphasizes the importance of legitimacy in international markets, and the resource-based view, which conceptualizes environmental capabilities as potential sources of competitive advantage [8,9].

Although a growing body of research has documented positive associations between various green practices and export outcomes, understanding the conditions that enhance or constrain these relationships remains underdeveloped. The effectiveness of green practices in boosting export performance likely depends on broader institutional and innovation ecosystem factors that shape how environmental practices are implemented, recognized, and valued in international markets. The institutional environment, particularly regulatory quality, may influence the credibility of environmental certifications and the enforcement of environmental standards [10]. Similarly, innovation ecosystem characteristics, such as research and development intensity and financial market development, may affect firms' capacity to successfully develop, implement, and commercialize environmental innovations [11,12].

Two critical gaps characterize the current literature. First, most existing studies employ firm-level data and conventional regression methods, limiting our understanding of macro-level dynamics and heterogeneous effects across different segments of the export distribution. Second, few studies systematically investigate the moderating role of both institutional and innovation ecosystem factors in an integrated framework, despite theoretical indications of their importance in shaping the relationship between environmental practices and international competitiveness.

Understanding these moderating influences holds substantial implications for both policy and practice. For policymakers, identifying institutional and innovation ecosystem factors that amplify the export benefits of green practices can inform the design of more integrated policy frameworks that simultaneously advance environmental and trade objectives. Such knowledge enables more targeted interventions that maximize returns on public investments in environmental governance and innovation support. For firms and industry associations, insights into how contextual factors shape the relationship between environmental practices and export success can guide strategic decisions regarding environmental certifications, innovation activities, and market entry strategies. Moreover,

these insights contribute to addressing the ongoing debate regarding potential trade-offs between environmental sustainability and economic competitiveness, offering evidence on the conditions under which environmental practices can become sources of competitive advantage rather than regulatory burdens.

This study addresses two specific research questions: First, how do green practices (specifically ISO14001 certification and environmental patents) affect export performance across different quantiles of the export distribution? Second, to what extent do institutional factors (regulatory quality) and innovation ecosystem characteristics (R&D expenditure and financial market development) moderate these relationships?

To address these questions, we employ a comprehensive empirical approach using panel data from 30 European countries for the period 2012–2022. Our methodology combines conventional panel regression techniques with panel quantile regression, enabling examination of potential heterogeneity across different segments of the export distribution. This approach provides novel insights into the conditions under which green practices become sources of competitive advantage in international markets.

2. Literature Review and Theoretical Framework

2.1. Theoretical Foundations

The relationship between environmental practices and export performance can be conceptualized through multiple theoretical lenses that provide complementary insights into the underlying mechanisms. Institutional theory serves as a foundational framework, positing that organizations adopt environmental practices to gain legitimacy and social acceptance in international markets [8]. This legitimacy-seeking behavior becomes particularly pronounced in export contexts, where firms must navigate diverse regulatory environments and stakeholder expectations across multiple jurisdictions. Complementarily, the resource-based view (RBV) conceptualizes environmental capabilities as valuable, rare, inimitable, and non-substitutable resources that can generate sustainable competitive advantages in global markets [9]. Under this perspective, environmental management systems and green innovations represent strategic assets that enable firms to differentiate their offerings and achieve superior performance.

Furthermore, Porter's hypothesis provides a crucial theoretical bridge between environmental regulation, innovation, and competitiveness, arguing that properly designed environmental standards can trigger innovation that fully offsets compliance costs while enhancing productivity [9]. This framework suggests that environmental practices should be viewed not merely as regulatory burdens but as catalysts for innovation-driven competitive advantages. These theoretical perspectives converge on the premise that environmental practices can enhance export performance through multiple pathways: legitimacy enhancement, resource-based differentiation, and innovation-induced efficiency gains.

2.2. Direct Effects of Environmental Practices on Export Performance

2.2.1. Environmental Management Systems and Export Outcomes

The empirical literature examining ISO14001 certification's impact on export performance reveals a consistent pattern of positive associations, albeit with important contextual variations. Blyde [13] established that ISO14001 certification increases the likelihood of firms becoming exporters in Ecuador, though without affecting export volumes, suggesting that certification primarily functions as a market entry facilitator rather than a volume driver. This finding aligns with institutional theory's emphasis on legitimacy-building mechanisms. Similarly, He et al. [14] demonstrated that despite negligible financial gains, ISO14001 certification promotes exports for Chinese firms, indicating that the benefits may manifest through non-financial channels such as market access and reputation enhancement.

Cross-national studies provide broader validation of these firm-level findings. Santos and Aguiar [15] analyzed survey data from 110 countries, finding that while ISO14001 shows modest statistical correlation with trade outcomes, certification is primarily driven by export-oriented firms seeking to satisfy stakeholder requirements in global markets. This finding emphasizes the demand-side pressures that drive certification adoption in export contexts. Similarly, Liu et al. [16] employed panel estimation techniques across 65 developing countries (1999–2016), establishing long-run relationships between ISO14001 adoption, trade openness, and environmental pressures, with significant regional variations highlighting contextual differences in certification motivations and outcomes.

Bellesi et al. [17] revealed that environmental management systems confer competitive advantages particularly in European markets, where environmental consciousness is more pronounced. This geographic specificity underscores the importance of market characteristics in determining certification benefits. Extending this perspective, Pacheco et al. [18] confirmed certification's importance for Portuguese SMEs' export activities, especially in low-technology sectors, suggesting that environmental credentials may be particularly valuable for firms lacking other sources of differentiation.

The legitimacy-building function of ISO14001 certification receives further support from Goldar [19], who identified significant positive effects on export intensity among Indian manufacturing plants. Evidence from diverse geographic contexts, including Ecuador, China, Europe, Portugal, and India, establishes the robustness of the certification-export relationship across different institutional environments. However, the magnitude and mechanisms of these effects appear to vary considerably across contexts, highlighting the importance of institutional and market-specific factors.

2.2.2. Environmental Labeling and Certification Systems

Beyond ISO14001, alternative forms of environmental certification demonstrate similar export-enhancing effects through distinct mechanisms. Zhou et al. [3] established that environmental labeling certification functions as a "green passport" for Chinese firms' exports by providing cost advantages and product differentiation capabilities. This metaphor aptly captures the certification's dual role as both a market access facilitator and a competitive differentiator. The study's emphasis on institutional context as a moderating factor foreshadows our investigation of how broader institutional conditions influence certification effectiveness.

Sam and Song [10] corroborated these findings using South Korean manufacturing data, revealing stronger certification effects on exports to high-income countries compared to middle- and lower-income markets. This income-differentiated impact pattern suggests that environmental credentials are particularly valued in affluent markets with stronger environmental consciousness and stricter regulatory standards. Such findings highlight the importance of destination market characteristics in determining the export benefits of environmental practices.

The operational mechanisms through which environmental certifications enhance export performance receive illumination from Al-Ghwayeen and Abdallah [20], who found that green supply chain management positively affects both environmental and export performance in Jordanian manufacturing firms, with environmental performance serving as a mediating variable. This mediation relationship suggests that certifications generate export benefits by first improving actual environmental performance, which then translates into market advantages through enhanced legitimacy and product differentiation.

2.2.3. Green Innovation and Export Competitiveness

The literature on green innovation's export effects reveals mechanisms that differ substantially from those associated with management system certifications. Chai [4] demonstrated that green innovation positively affects export quality in Chinese manufacturing firms through enhanced clean productivity and waste treatment efficiency. This finding emphasizes the productivity-enhancing aspects of environmental innovation, aligning with Porter's hypothesis regarding the efficiency gains from environmental improvements.

Shu et al. [6] provide a particularly relevant theoretical framework for understanding green innovation's export effects, establishing that green innovation helps emerging market firms obtain both regulatory and social legitimacy in host countries, consequently boosting exports. Their identification of political risk and buyer sophistication as important moderators directly informs our investigation of institutional factors. This legitimacy-based perspective suggests that green innovations serve as signals of technological sophistication and environmental commitment, thereby enhancing firm credibility in international markets.

The indirect pathways through which green innovation affects exports receive attention from Li and Li [7], who found that environmental management systems indirectly enhance export performance through innovation in Chinese manufacturing businesses. This finding suggests complementarities between different forms of environmental practices, with management systems serving as platforms for innovation activities. Furthermore, Lu [21] discovered that green mergers and acquisitions increase the export performance of polluting enterprises by promoting green innovation, indicating that corporate restructuring can serve as a vehicle for environmental innovation and subsequent export enhancement.

2.3. Environmental Regulation, Innovation, and Export Dynamics

2.3.1. Regulatory-Induced Innovation Effects

The relationship between environmental regulation, innovation, and export competitiveness represents a complex domain where Porter's hypothesis encounters empirical validation across diverse contexts. Costantini and Mazzanti [1] and Fabrizi et al. [22] both confirmed that environmental policies and innovation efforts positively influence export flow dynamics, particularly when properly coordinated. This coordination aspect highlights the importance of policy design in maximizing the export benefits of environmental practices.

However, the regulatory-export relationship exhibits significant nonlinearities that complicate simple interpretations. Liu and Xie [23] revealed a U-shaped effect of environmental regulation on China's manufacturing export competitiveness, with significant heterogeneity across pollution-intensity categories. This nonlinear pattern suggests that moderate levels of environmental regulation may initially impose costs that outweigh benefits, while higher regulatory intensity eventually triggers sufficient innovation to generate net competitive advantages.

Lodi and Bertarelli [24] developed a unified framework examining both pollution haven effects and Porter's hypothesis, demonstrating that regulation-induced eco-innovation can either enhance or impair export propensity depending on firm characteristics. This contingent relationship underscores the importance of firm-level factors in determining regulatory outcomes. Similarly, Song and Wang [25] identified a U-shaped relationship between green technology progress and comparative advantages in Chinese industries, providing additional evidence for nonlinear regulatory-competitiveness relationships.

2.3.2. Innovation Capabilities and Environmental Practices

The intersection of innovation capabilities and environmental practices in determining export outcomes receives attention from Adhikari and Momaya [11], who highlighted

environmentally sustainable practices as moderators between innovation capabilities and export competitiveness. This moderating relationship suggests that environmental practices can amplify the export benefits of innovation capabilities, providing theoretical justification for investigating institutional moderators in our study.

Sectoral studies offer additional insights into innovation-environment-export linkages. The renewable energy sector provides a particularly illuminating case, with Shuai et al. [26] evaluating renewable energy product competitiveness across the US, China, and India, noting distinct differences in factors driving international competitiveness. These sectoral variations highlight the importance of technological and institutional contexts in shaping competitive dynamics.

Consoli et al. [12] emphasized that bilateral policy alignment and balanced domestic policy mixes enhance export capacity in the EU sustainable energy transition. This finding suggests that policy coordination (both domestic and international) plays a crucial role in translating environmental innovations into export advantages, providing additional theoretical motivation for examining institutional moderators.

2.4. Firm-Level Factors and Developing Country Perspectives

2.4.1. Corporate Image and Sustainability Integration

The integration of sustainability practices with broader corporate strategies receives theoretical attention from Villena Manzanares and Souto Pérez [27], who established that corporate image mediates the positive effects of sustainability and innovative orientation on export performance. This mediation relationship suggests that environmental practices enhance export performance partly through reputation mechanisms that improve market perception and customer relationships.

However, the export benefits of environmental practices may not be uniformly positive across different economic development contexts. Chen et al. [28] found that forest certification can become a trade barrier for developing countries, particularly when trading with developed countries. This finding highlights potential asymmetries in certification benefits, where developed country firms may gain advantages while developing country firms face additional barriers.

2.4.2. Innovation Capabilities in Emerging Markets

The literature reveals important differences in how environmental innovations translate into export advantages across development contexts. Bal and Kazan [29] concluded that eco-innovation activities in developing economies are unlikely to secure competitive advantages in international markets, suggesting that institutional and technological capabilities may constrain the export benefits of green practices in less developed contexts.

Meneto and Siedschlag [30] provide a more nuanced perspective, determining that certain types of green innovations positively associate with firms' export participation but not export intensity. This distinction between extensive and intensive margins of trade suggests that green innovations may primarily facilitate market entry rather than scale expansion, aligning with earlier findings regarding ISO14001 certification.

2.5. Institutional and Innovation Ecosystem Moderators: Theoretical Gaps and Research Opportunities

2.5.1. Identified Research Gaps

While the reviewed literature establishes generally positive relationships between various environmental practices and export outcomes, several critical gaps limit our theoretical understanding. First, most existing studies employ firm-level data and conventional regression methods, thereby constraining our comprehension of macro-level dynamics and heterogeneous effects across different segments of the export distribution. This methodolog-

ical limitation obscures potentially important variations in how environmental practices affect countries at different stages of export development.

Second, and more fundamentally, few studies systematically investigate the moderating roles of both institutional and innovation ecosystem factors within an integrated theoretical framework. Although individual studies acknowledge the importance of institutional context [3,10] and innovation capabilities [11,12], the literature lacks comprehensive analyses of how these factors jointly shape the relationship between environmental practices and export performance.

2.5.2. Theoretical Framework for Institutional and Innovation Ecosystem Moderators

Building on the identified gaps, this study develops a theoretical framework that positions three factors as key moderators of environment-export relationships: regulatory quality, research and development expenditure, and financial market development. Regulatory quality may influence the credibility of environmental certifications and the enforcement of environmental standards, thereby affecting their market value [10]. High-quality regulatory institutions can enhance the signaling value of voluntary environmental practices by providing credible oversight and reducing information asymmetries between firms and their international customers.

Research and development expenditure represents the innovation ecosystem's capacity to support the development and commercialization of environmental innovations [11,12]. Countries with higher R&D intensity may provide better complementary assets (such as skilled human capital, technological infrastructure, and knowledge spillovers) that enable firms to more effectively translate environmental practices into export advantages.

Financial market development affects firms' ability to make the substantial investments often required for implementing environmental management systems and developing green innovations [12]. Well-developed financial markets can facilitate access to capital for environmental investments, enable better risk assessment of green projects, and provide sophisticated financial instruments that support environmental activities.

2.5.3. Institutional Complementarities and Environmental Practice Effectiveness

The theoretical framework posits that institutional and innovation ecosystem factors serve as complementary assets that enhance the effectiveness of environmental practices in generating export advantages. Drawing on the resource-based view, environmental practices alone may be insufficient to create competitive advantages; rather, their effectiveness depends on the presence of complementary institutional resources that enable their full exploitation.

Regulatory quality may enhance the signaling value of environmental certifications by providing credible oversight mechanisms and reducing information asymmetries between firms and international customers. Financial market development can facilitate the substantial investments required for implementing environmental management systems and provide sophisticated capital allocation mechanisms that support green innovation activities. Research and development expenditure represents the innovation ecosystem's capacity to generate knowledge spillovers and complementary technologies that amplify the competitive benefits of environmental practices.

This complementarity perspective suggests that the export benefits of environmental practices should be strongest in countries with well-developed institutional and innovation ecosystems, where firms can leverage multiple supporting assets to maximize the commercial value of their environmental investments.

2.6. Research Questions and Theoretical Contributions

Based on this theoretical synthesis, our study addresses three research questions that collectively advance both theoretical understanding and empirical knowledge of environment-export relationships. First, we investigate how green practices affect export performance across different quantiles of the export distribution, thereby extending beyond average effects to examine heterogeneity patterns that may reveal differential benefits for countries at various stages of export development. Second, we examine the extent to which institutional and innovation ecosystem factors moderate these relationships through interaction effects, providing systematic evidence on contextual influences that have been underexplored in the literature. Third, we analyze the robustness of these direct and moderating effects using both conventional panel regression and panel quantile regression techniques to ensure comprehensive empirical validation.

These research questions contribute to the literature in three ways. First, they provide macro-level evidence on environment-export relationships that complements existing firm-level studies. Second, they systematically examine institutional and innovation ecosystem moderators within an integrated framework that addresses previous theoretical gaps. Third, they employ panel quantile regression techniques to capture heterogeneity in effects across export performance distributions. The combination of conventional panel regression for moderating effects analysis and panel quantile regression for main effects analysis provides a comprehensive empirical approach that advances theoretical understanding while offering practical insights for policy design and firm strategy.

3. Materials and Methods

3.1. Data

Our empirical analysis draws on a balanced panel dataset covering 30 European countries for the period 2012–2022. The focus of our investigation is how environmental innovation affects export performance, with particular attention to institutional and innovation ecosystem moderators that may amplify or attenuate this relationship.

We measure export performance, our dependent variable, using the value of exports of goods and services in current US dollars, obtained from the World Bank. Our key explanatory variables capture two dimensions of environmental management and innovation: the adoption of formal environmental management systems (proxied by ISO 14001 certification counts) and environmental innovation output (measured by granted environmental technology patents from the OECD database). The latter classification encompasses patents related to environmental pollution control, water conservation, renewable energy, and other green technologies.

The specification includes several controls that standard trade models suggest affect export performance. Exchange rates account for price competitiveness effects, while GDP of trade partners controls for demand conditions. We also control for trade barriers using weighted average tariff rates and include FDI inflows to capture the role of international capital in export promotion. The distinctive feature of our analysis is the examination of three institutional and innovation ecosystem moderators: regulatory quality, research and development (R&D) investment, and financial market development. Table 1 provides detailed definitions and data sources for all variables used in our analysis.

Table 1. Variable definitions and data sources.

Variables	Definitions	Sources
Export value	Exports of goods and services (current US$)	World Bank
Green patents	Number of environment-related technology patents	OECD
ISO14001	Number of ISO14001 certificates per country	ISO: Global standards for trusted goods and services
Exchange rate	Official exchange rate (LCU per US$, period average)	World Bank
GDP of trade partners	GDP growth of top 10 trade partners (%)	World Bank
Trade barriers	Tariff rate, applied, weighted mean, all products (%)	World Bank
Foreign direct investment	Foreign direct investment, net inflows (% of GDP)	World Bank
Regulatory quality	Worldwide Governance Indicators- Regulatory Quality Index	World Bank Group
R&D expenditure	R&D Expenditure (% of GDP)	World Bank
Financial market development	Financial Development Index	World Bank Group

Table 2 presents descriptive statistics for all variables in our analysis. The wide range in export values and environmental indicators demonstrates considerable heterogeneity across European countries, providing an appropriate context for our investigation of how green practices influence export performance across different quantiles.

Table 2. Descriptive statistics.

	EXP	GRN	ISO	EXR	TRB
Mean	287.957	301.1119	2990.19	14.27472	1.9136
Median	116.733	17.305	1268.00	0.9034	1.84
Min	9.686	0	23	0.5293	0.72
Max	1906.115	4432.04	26,655.00	372.5958	6.84
SD	363.585	707.7095	4519.51	50.9915	0.747
Obs.	330	330	330	330	330
	GDP	FDI	RQI	RDE	FMD
Mean	0.0335	12.1203	0.9742	1.59743	0.5246
Median	0.0352	2.6996	1.0784	1.3682	0.52
Min	−0.1824	−101.8331	−1.3312	0.3269	0.15
Max	0.1733	452.221	2.039	3.429	0.98
SD	0.0455	49.0984	0.7115	0.8894	0.2088
Obs.	330	330	330	330	330

Note: EXP = Export value (billion); GRN = Green patents; ISO = ISO14001 certification; EXR = Exchange rate; TRB = Trade barriers; GDP = GDP growth of trade partners; FDI = Foreign direct investment; RQI = Regulatory quality; RDE = R&D expenditure; FMD = Financial market development.

3.2. Methodology

3.2.1. Panel Unit Root Test

To ensure the validity of our regression analysis, we verify the stationarity of our variables using complementary panel unit root tests that address different assumptions about cross-sectional heterogeneity. We employ both the Levin-Lin-Chu (LLC) test [31] and the Im, Pesaran, and Shin (IPS) test [32] to provide robust evidence of stationarity across our panel dataset.

The LLC test is particularly appropriate for our balanced panel with moderate time dimensions and offers stronger statistical power than individual unit root tests applied to each cross-section. This test examines the null hypothesis that all panels contain a unit root against the alternative that all panels are stationary. The LLC test assumes a common autoregressive parameter across all panels and accounts for cross-sectional dependence by subtracting cross-sectional means. The test is formalized as:

$$\Delta y_{it} = \alpha_i + \rho y_{it-1} + \sum_{k=1}^{n} \phi_{ik} \Delta y_{it-k} + \delta_i t + \theta_i + \varepsilon_{it}, \quad (1)$$

where y_{it} represents the variable being tested for a unit root, α_i captures country-specific fixed effects, $\delta_i t$ allows for panel-specific time trends, and θ_i captures time-specific effects. The parameter ρ is the autoregressive parameter, k represents the number of lags selected based on information criteria, and ε_{it} is the error term. The test examines whether $\rho < 0$ (stationarity) or $\rho = 0$ (nonstationarity).

However, the LLC test's assumption of homogeneous autoregressive parameters across all cross-sections represents a restrictive constraint that may not hold in practice when countries exhibit different economic structures and adjustment dynamics. To address this limitation, we complement the LLC test with the Im, Pesaran, and Shin (IPS) test, which relaxes the homogeneity assumption by allowing for heterogeneous autoregressive parameters across panels.

The IPS test is based on the mean of individual Augmented Dickey–Fuller (ADF) statistics and permits different autoregressive coefficients for each country. The test specification for each cross-section is:

$$\Delta y_{it} = \alpha_i + \rho_i y_{it-1} + \sum_{j=1}^{p_i} \phi_{ij} \Delta y_{it-j} + \varepsilon_{it}, \quad (2)$$

where ρ_i is allowed to vary across countries, reflecting heterogeneous adjustment speeds and persistence characteristics. The IPS test statistic is constructed as the standardized average of individual ADF t-statistics:

$$\bar{t}_{NT} = \frac{1}{N} \sum_{i=1}^{N} t_{i\rho_i} \quad (3)$$

The null hypothesis remains that each series contains a unit root ($\rho_i = 0$ for all i), while the alternative hypothesis allows for some panels to be stationary ($\rho_i < 0$ for some i). This specification is particularly valuable when cross-sectional units exhibit different degrees of persistence, making it more appropriate for heterogeneous country panels.

By employing both tests, we can assess stationarity under both homogeneous (LLC) and heterogeneous (IPS) parameter assumptions, providing comprehensive evidence for the time series properties of our variables. Consistent rejection of the unit root hypothesis across both methodologies strengthens confidence in the stationarity of our data and validates the use of standard panel regression techniques without concerns of spurious relationships arising from nonstationary data.

3.2.2. Panel Regression Analysis

Our baseline estimation approach uses panel regression techniques to establish the relationship between environmental practices and export performance. Following Wooldridge [33] and Hsiao [34], we estimate the following model:

$$y_{it} = \alpha_0 + x'_{it}\beta + z'_{it}\gamma + \mu_i + \lambda_t + \varepsilon_{it}, \quad (4)$$

where y_{it} represents our outcome variable of interest. The term x'_{it} is a K-element row vector containing explanatory variables, while z'_{it} is an M-element row vector of control variables. The parameter α_0 denotes the intercept, while β and γ are K- and M-element column vectors of coefficients, respectively. The component μ_i captures country-specific fixed effects, λ_t captures time fixed effects, and ε_{it} represents the idiosyncratic error term capturing unobserved factors that vary across both countries and time periods.

We estimate four different specifications: a simplified model without control variables, pooled ordinary least squares (OLS), fixed effects, and random effects models. To determine the most appropriate specification, we employ the Hausman test [35] to compare fixed versus random effects models, and an F-test to evaluate pooled OLS against fixed effects [36]. The Hausman test examines whether the unique errors (μ_i) are correlated with the regressors, with the null hypothesis being no correlation (favoring random effects) against the alternative of correlation (favoring fixed effects). The F-test examines the joint significance of the fixed effects, with the null hypothesis being that all $\mu_i = 0$ (favoring pooled OLS) against the alternative that at least some $\mu_i \neq 0$ (favoring fixed effects).

3.2.3. Panel Quantile Regression

While conventional panel regression estimates average relationships, we employ panel quantile regression techniques to investigate how the impact of environmental practices varies across different levels of export performance. Following the approach developed by Koenker and Bassett [37] and extended to panel data by Koenker [38] and Canay [39], this method allows us to examine potentially heterogeneous effects throughout the conditional distribution of the dependent variable, thereby providing a more comprehensive understanding of the relationship between environmental practices and export outcomes.

The panel quantile regression model can be expressed as:

$$Q_{y_{it}}(\tau|X_{it}) = \alpha_i(\tau) + X'_{it}\beta(\tau) + \varepsilon_{it}(\tau), \quad (5)$$

where $Q_{y_{it}}(\tau|X_{it})$ denotes the τ-th conditional quantile of y_{it} given the vector of explanatory and control variables X_{it}, $\alpha_i(\tau)$ represents country-specific fixed effects that may vary across quantiles, $\beta(\tau)$ is the vector of parameters that may also vary across quantiles, and $\varepsilon_{it}(\tau)$ is the error term at the τ-th quantile.

To handle the fixed effects in panel quantile regression, we employ Canay's [39] two-step approach, which addresses the incidental parameter problem inherent in quantile regression with fixed effects. In the first step, we estimate a standard fixed effects panel regression to obtain consistent estimates of the fixed effects $\hat{\alpha}_i$. In the second step, we perform quantile regression on the transformed data $y_{it} - \hat{\alpha}_i$ to estimate the quantile-specific coefficients $\beta(\tau)$. This mean elimination approach ensures consistency of the quantile regression estimates while avoiding the computational complexity of estimating individual-specific intercepts at each quantile. We estimate this model at five quantile levels: τ = [0.10, 0.25, 0.50, 0.75, 0.90], following Powell [40].

3.2.4. Moderating Effects Analysis

To investigate how institutional and innovation ecosystem factors moderate the relationship between green practices and export performance, we augment our panel regression model with interaction terms. Following the approach of Brambor et al. [41] and Hayes [42], the model specification for moderating effects is:

$$y_{it} = \alpha_0 + x'_{it}\beta + \theta[(GRN_{it} \times (M_{it} - (Q_\tau(M_{it})) + z'_{it}\gamma + \mu_i + \lambda_t + \varepsilon_{it}, \quad (6)$$

$$y_{it} = \alpha_0 + x'_{it}\beta + \theta(log(ISO_{it}) \times (M_{it} - (Q_\tau(M_{it})) + z'_{it}\gamma + \mu_i + \lambda_t + \varepsilon_{it}, \quad (7)$$

where x'_{it} contains all main explanatory variables including green patents (GRN_{it}), ISO14001 certification ($log(ISO_{it})$). M_{it} represents the moderator variable (regulatory quality, R&D expenditure, or financial market development), and $Q_\tau(M_{it})$ is the τ-th quantile of the moderator. We center the moderator at its corresponding quantile to facilitate interpretation of the main effects, following the recommendations of Aiken et al. [43] and Balli and Sørensen [44].

The coefficients in θ capture the moderating effects at each quantile τ. A positive coefficient indicates that the moderator strengthens the relationship between the environmental practice and export performance, while a negative coefficient suggests an attenuating effect.

4. Results and Discussion

4.1. Panel Unit Root Test Results

Prior to conducting panel regression analysis, we verified the stationarity properties of our variables through complementary panel unit root tests that accommodate different assumptions regarding cross-sectional heterogeneity. Table 3 presents results from both the Levin-Lin-Chu (LLC) test, which assumes homogeneous autoregressive parameters across countries, and the Im, Pesaran, and Shin (IPS) test, which permits heterogeneous parameters across panels.

Table 3. Panel unit root test.

Variables	Levin-Lin-Chu Test	Im-Pesaran-Shin Test
log(Export value)	−7.2837 ***	−4.0656 ***
Green patents	−10.468 ***	−6.7506 ***
log(ISO14001)	−12.665 ***	−7.5789 ***
log(Exchange rate)	−11.425 ***	−3.7186 ***
GDP growth of trade partners	−21.2 ***	−16.9 ***
Trade barriers	−25.2 ***	−15.473 ***
Foreign direct investment	−14.872 ***	−10.417 ***
Regulatory quality	−7.2193 ***	−3.1288 ***
R&D expenditure	−7.9279 ***	−4.8798 ***
Financial market development	−10.442 ***	−7.4944 ***

*** indicate the significance levels at 1%.

Both testing procedures yield consistent evidence of stationarity across all variables. The test statistics uniformly reject the null hypothesis of nonstationarity at the 1% significance level. The concordance between these two approaches, one assuming parameter homogeneity and the other allowing for heterogeneity, provides robust confirmation that our variables exhibit stationary behavior throughout the panel.

This dual confirmation proves particularly valuable given the substantial economic and institutional diversity characterizing the 30 European countries in our sample. Countries at different stages of economic development and with varying structural characteristics may reasonably be expected to exhibit distinct persistence dynamics. The agreement between LLC and IPS results indicates that our stationarity conclusions hold regardless of whether we impose common or country-specific persistence structures. This robust foundation validates our subsequent application of standard panel regression techniques, eliminating concerns about spurious relationships that could arise from nonstationary data.

4.2. Panel Regression Results

To analyze the impact of green innovations and environmental management systems on export performance, we employed a baseline panel regression approach. Four dis-

tinct model specifications were estimated: a simplified model excluding control variables, pooled ordinary least squares (OLS), fixed effects, and random effects models, with results presented in Table 4.

Table 4. Panel regression parameter estimation.

Variables	Without Control Variables	Pooled OLS	Fixed Effects	Random Effects
Constant	21.61108 ***	20.59807 ***		24.78605 ***
	(0.26890)	(0.32351)		(0.22778)
Green patents	0.00064 ***	0.00061 ***	−0.00005	0.00002
	(0.00007)	(0.00007)	(0.00005)	(0.00005)
log(ISO14001)	0.53054 ***	0.55709 ***	0.07914 ***	0.11156 ***
	(0.03817)	(0.03967)	(0.02336)	(0.02480)
log(Exchange rate)		−0.01795	−0.02746	−0.02571
		(0.03272)	(0.05313)	(0.04936)
GDP growth of trade partners		4.54820 ***	1.95789 ***	1.96614 ***
		(0.96417)	(0.21402)	(0.23394)
Trade barriers		0.36026 ***	−0.02146	−0.01821
		(0.06360)	(0.01969)	(0.02138)
Foreign direct investment		0.00032	0.00046 *	0.00045
		(0.00097)	(0.00025)	(0.00027)
Adj. R-squared	0.5854	0.6404	0.1790	0.2227

***, and * indicate the significance levels at 1%, and 10%, respectively.

Model selection proceeded through rigorous specification tests, the results of which appear in Table 5. The Hausman test yields a Chi-squared statistic of 44.767, significant at the 1% level, providing strong evidence against the null hypothesis that random effects estimates are both consistent and efficient. This result indicates systematic correlation between the country-specific effects and the regressors, establishing the fixed effects model as more appropriate than the random effects specification. The F-test similarly confirms that the fixed effects model is preferable to pooled OLS, with a test statistic of 240.95 rejecting the null hypothesis of zero fixed effects. These statistical diagnostics, considered alongside model fit criteria, establish the fixed effects specification as the most suitable for our analysis.

Table 5. Model selection.

Tests	Test Statistics
Hausman test	44.767 ***
F test	240.95 ***

*** indicate the significance levels at 1%.

The fixed effects estimation reveals that ISO14001 certification exerts a statistically significant positive effect on export performance, with a coefficient of 0.07914, significant at the 1% level. This indicates that a 1% increase in ISO14001 certification corresponds to approximately a 0.08% increase in export value. This finding aligns with Zhou et al. [3], who established that environmental certification functions as a "green passport" facilitating market access and product differentiation, and with Bellesi et al. [17], who demonstrated that standardized environmental management systems confer competitive advantages, particularly in European markets where environmental standards are stringent and stakeholder scrutiny is pronounced.

In contrast to the panel regression results without control variables and pooled OLS, green patents lose statistical significance in the fixed effects specification once we account for country-specific heterogeneity and control variables. This suggests that the apparent patent-export relationship in simpler specifications may reflect omitted country-specific

characteristics (such as overall technological sophistication, industrial structure, or innovation culture) rather than a direct causal pathway from environmental patents to exports. This finding underscores the importance of controlling for unobserved country heterogeneity when examining macro-level relationships, as failure to do so can lead to misleading inferences about the drivers of export performance.

The control variables reveal several notable patterns. GDP growth of trade partners demonstrates a strong positive association with exports, with a coefficient of 1.95789 significant at the 1% level. This substantial effect confirms that demand conditions in destination markets serve as a fundamental driver of export performance, consistent with standard trade theory. A one percentage point increase in trading partners' GDP growth is associated with approximately a 2% increase in exports, highlighting the critical importance of external demand dynamics for export success.

The exchange rate variable proves statistically insignificant in the fixed effects specification, suggesting that within-country variation in exchange rates over our study period does not systematically affect export performance once we control for country and time fixed effects. This result may reflect several factors specific to the European context. First, many countries in our sample share the euro as their common currency, eliminating exchange rate variation in intra-EU trade, which constitutes a substantial proportion of total trade for most European nations. Second, even for non-euro countries, exchange rate pass-through to export competitiveness may be attenuated by global value chain integration, where imported intermediate inputs reduce the net competitive advantage from currency depreciation.

Foreign direct investment displays a positive coefficient of 0.00046, significant at the 10% level, indicating a modest complementarity between international capital flows and export expansion. This weak but positive relationship suggests that FDI may facilitate exports through mechanisms such as technology transfer, access to multinational production networks, or improvements in productive efficiency, though the economic magnitude of this effect appears relatively small in our sample.

Contrary to theoretical expectations, trade barriers exhibit a negative coefficient, though the effect is statistically insignificant. This counterintuitive sign may reflect reverse causality concerns or the complex nature of modern trade barriers, which increasingly take the form of nontariff measures that our simple tariff rate variable fails to capture adequately.

The relatively modest adjusted R-squared of 0.179 in the fixed effects model merits brief discussion. This value, while lower than those in pooled OLS or random effects specifications, reflects the stringent requirements imposed by fixed effects estimation, which explains only within-country variation after removing all between-country variation through country-specific intercepts. The lower R-squared in fixed effects models is typical and does not indicate poor model fit, but rather demonstrates that much of the variation in exports across countries stems from time-invariant country characteristics captured by the fixed effects themselves. The model's primary purpose (identifying the within-country effects of our key variables while controlling for unobserved heterogeneity) is well-served by this specification.

4.3. Panel Quantile Regression Analysis

Building upon our baseline findings, we employed panel quantile regression techniques to investigate whether the effects of green innovations and ISO14001 certification vary systematically across different segments of the export performance distribution. This approach permits examination of heterogeneous treatment effects that conventional mean regression obscures, revealing whether countries at different export performance levels derive differential benefits from environmental practices. We estimated the model at the 10th, 25th, 50th, 75th, and 90th quantiles of the export distribution.

Figure 1 illustrates the estimated coefficients for our main variables across export performance quantiles, revealing substantial heterogeneity in how environmental practices influence exports at different performance levels.

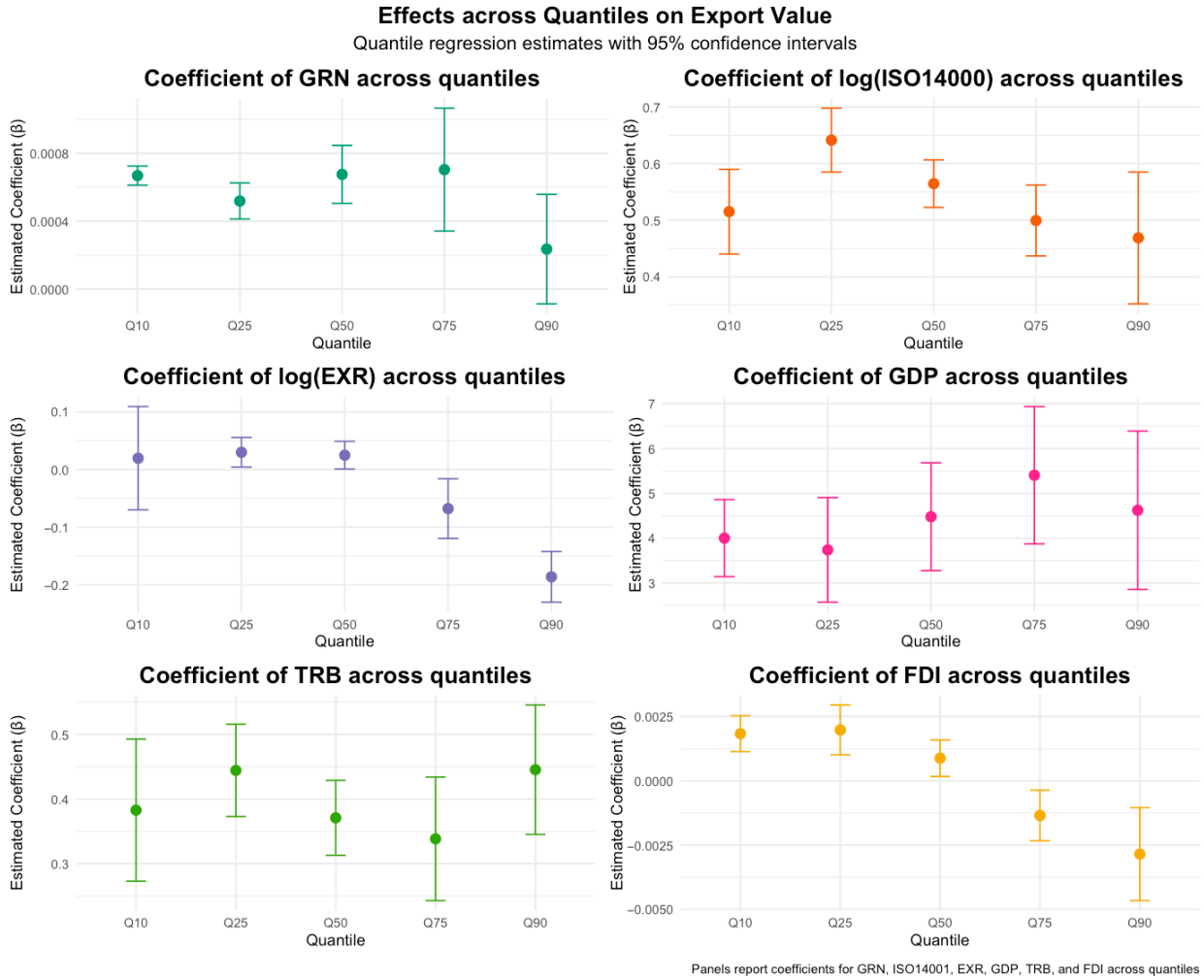

Figure 1. Estimated Coefficients of Main Variables Across Export Performance Quantiles.

The results presented in Table 6 demonstrate striking patterns of heterogeneity, particularly for ISO14001 certification. The certification coefficient remains positive and statistically significant across all quantiles, ranging from 0.51487 at the 10th quantile to 0.46853 at the 90th quantile. While this might initially suggest relatively uniform effects, closer inspection reveals important nuances. The point estimates indicate somewhat stronger effects at the lower and middle quantiles compared to the upper quantiles, though the differences are not as pronounced as one might expect. This pattern suggests that environmental management system certification provides substantial export benefits across the entire performance distribution, with marginally stronger effects for countries not yet at the highest export levels. For countries at lower export quantiles, ISO14001 certification may serve as a critical signal of environmental commitment that helps overcome information asymmetries and facilitates market entry, particularly in environmentally conscious European markets. Even at higher quantiles, however, the persistent positive effects indicate that certification continues to provide value, possibly through enhanced reputation, regulatory compliance, or access to supply chains with stringent environmental requirements.

Table 6. Panel quantile regression parameter estimation.

Variables	10th	25th	50th	75th	90th
Constant	19.82221 ***	19.31489 ***	20.38179 ***	21.58486 ***	22.43609 ***
	(0.55446)	(0.42823)	(0.30368)	(0.60307)	(0.91598)
Green patents	0.00067 ***	0.00052 ***	0.00068 ***	0.00070 **	0.00024
	(0.00006)	(0.00011)	(0.00020)	(0.00035)	(0.00030)
log(ISO14001)	0.51487 ***	0.64139 ***	0.56442 ***	0.49930 ***	0.46853 ***
	(0.07467)	(0.05891)	(0.03968)	(0.06693)	(0.11631)
log(Exchange rate)	0.01959	0.02991	0.02484	−0.06763	−0.18586 ***
	(0.09650)	(0.02747)	(0.02467)	(0.06007)	(0.04533)
GDP growth of trade partners	4.00032 ***	3.73741 ***	4.47801 ***	5.40316 ***	4.62262 **
	(0.80985)	(1.14748)	(1.15954)	(1.76838)	(1.89521)
Trade barriers	0.38288 ***	0.44433 ***	0.37096 ***	0.33846 ***	0.44546 ***
	(0.10261)	(0.07386)	(0.05847)	(0.09496)	(0.10914)
Foreign direct investment	0.00183 **	0.00198 **	0.00088	−0.00134	−0.00285
	(0.00072)	(0.00100)	(0.00080)	(0.00111)	(0.00179)

***, and ** indicate the significance levels at 1%, and 5%, respectively.

Green patents exhibit a more complex pattern across quantiles. The coefficients are positive and statistically significant at the 10th (0.00067), 25th (0.00052), 50th (0.00068), and 75th (0.00070) quantiles, all significant at conventional levels. However, at the 90th quantile, the coefficient diminishes to 0.00024 and loses statistical significance. This suggests that technological environmental innovations provide relatively consistent export benefits across most of the performance distribution but may offer diminishing returns at the very highest export levels. This pattern could reflect several mechanisms. Countries at lower-to-middle export performance levels may derive substantial competitive advantages from environmental innovations that help differentiate their products and meet increasingly stringent environmental standards in destination markets. At the highest export levels, where countries already possess sophisticated technological capabilities and established market positions, marginal additions to the environmental patent portfolio may provide less incremental value. Alternatively, this pattern might reflect a threshold effect whereby countries must reach a critical mass of environmental innovation before benefits materialize, but beyond very high levels, additional patents face diminishing returns.

The control variables display noteworthy variation across quantiles. GDP growth of trade partners demonstrates consistently positive and significant effects across all quantiles, with coefficients ranging from 3.73741 (25th quantile) to 5.40316 (75th quantile), all significant at the 1% level. The somewhat larger coefficients at the extremes suggest that both countries with lower export volumes and those with very high volumes exhibit particular sensitivity to demand conditions in partner markets. For lower-export countries, partner GDP growth may be especially critical because they lack the market diversification and established customer relationships that buffer more established exporters. For the highest exporters, the large coefficient may reflect their deeper integration into global markets and greater exposure to international business cycles.

Exchange rate effects exhibit an interesting progression across quantiles. The variable remains insignificant at lower quantiles but becomes negative and highly significant at the 90th quantile. This quantile-dependent pattern suggests that the relationship between exchange rates and exports varies substantially with export performance levels. The insignificance at lower quantiles may reflect the limited currency sensitivity of countries with smaller export volumes or the predominance of intra-EU trade conducted in euros. At the highest export levels, however, the significant negative coefficient requires careful interpretation. This counterintuitive sign may indicate that countries with the largest export volumes often experience currency appreciation as a consequence of their export

success (reverse causality), or it may reflect the fact that highly export-oriented economies have substantial import content in their exports, reducing the net competitive benefit from depreciation. The euro-area context further complicates interpretation, as many high-export countries in our sample share a common currency.

Trade barriers display positive and significant coefficients across all quantiles, with values ranging from 0.33846 to 0.44546. This counterintuitive positive relationship between tariffs and exports likely reflects measurement issues or complex causal pathways rather than suggesting that higher barriers promote exports. The tariff variable may capture reverse causality if countries facing high export volumes subsequently raise tariffs on imports, or it may inadequately measure the complex array of nontariff barriers that increasingly characterize modern trade policy.

Foreign direct investment exhibits positive coefficients at lower quantiles but becomes insignificant or negative at higher quantiles. This pattern suggests that FDI plays a more important complementary role for countries at earlier stages of export development, possibly by facilitating technology transfer, management expertise, or access to global production networks. For countries already achieving high export volumes, additional FDI inflows may have neutral or even slightly negative associations with exports, perhaps reflecting competition for domestic resources or shifts toward more domestically oriented foreign investments.

Overall, the quantile regression results reveal that while both environmental certifications and green patents generally promote exports, their effects exhibit meaningful heterogeneity across the export performance distribution. ISO14001 certification demonstrates relatively robust effects throughout, while green patents show diminishing returns at the highest performance levels. These patterns underscore the importance of moving beyond average treatment effects to understand how environmental practices differentially influence countries at varying stages of export development.

4.4. Moderating Effects Results

Our investigation extends beyond direct effects to examine how institutional and innovation ecosystem factors moderate the relationship between environmental practices and export performance. We focus on three potential moderators: regulatory quality, research and development expenditure, and financial market development. Table 7 presents the parameter estimates for interaction terms between these moderators and our environmental practice variables.

Table 7. Estimation of moderating effects models.

Variables	RQI	RDE	FMD
Green patents × (RQI)	0.00004 (0.00007)		
log(ISO14001) × (RQI)	0.04268 *** (0.01452)		
Green patents × (RDE)		−0.00003 (0.00007)	
log(ISO14001) × (RDE)		−0.01678 (0.01675)	
Green patents × (FMD)			0.00030 (0.00037)
log(ISO14001) × (FMD)			0.11790 * (0.06610)
Independents variables	Yes	Yes	Yes
Control variables	Yes	Yes	Yes
Adj. R-squared	0.11849	0.10743	0.085199

***, and * indicate the significance levels at 1%, and 10%, respectively.

The results reveal differentiated moderating patterns across environmental practices and institutional factors. Regulatory quality demonstrates a positive and statistically significant moderating effect on the ISO14001-export relationship, indicating that higher regulatory quality amplifies the export benefits derived from environmental management system certification. This interaction effect proves economically meaningful: in countries with superior regulatory quality, ISO14001 certification yields substantially larger export gains than in countries with weaker regulatory institutions. Green patents, conversely, exhibit no significant moderation by regulatory quality, suggesting that the export benefits of technological environmental innovations operate independently of general regulatory quality.

Financial market development similarly exhibits a significant positive moderating effect on ISO14001 certification. This finding indicates that well-functioning financial markets enhance the extent to which environmental management certifications translate into export performance. As with regulatory quality, financial market development does not significantly moderate the green patents-export relationship.

Research and development expenditure fails to demonstrate significant moderating effects for either environmental practice. The interaction terms for both green patents and ISO14001 certification prove statistically insignificant, with the ISO14001 interaction even exhibiting a negative point estimate.

Figure 2 illustrates these moderating relationships across different quantiles of the moderator variables, revealing the conditional nature of institutional influences on environment-export linkages.

4.4.1. Regulatory Quality as Moderator

Table 8 presents marginal effects of environmental practices on exports evaluated at different quantiles of regulatory quality. The results demonstrate that ISO14001 certification's export effect strengthens progressively as regulatory quality improves. At the 10th quantile of regulatory quality, ISO14001's marginal effect stands at 0.02116, while at the 90th quantile, the effect reaches 0.09244. This progression reveals that environmental management certifications generate substantial export benefits primarily in institutional environments characterized by high regulatory quality.

Table 8. Estimate results of marginal effects at different quantile of regulatory quality.

Variables					
Green patents	0.00001	0.00003	0.00005	0.00007 **	0.00008 **
	(0.00011)	(0.00007)	(0.00004)	(0.00003)	(0.00003)
log(ISO14001)	0.02116	0.04279 ***	0.06292 ***	0.08358 ***	0.09244 ***
	(0.01837)	(0.01608)	(0.01680)	(0.02010)	(0.02206)
Control variables	Yes	Yes	Yes	Yes	Yes
Quantile of RQI (Q_q(RQI))	10th	25th	50th	75th	90th

***, and ** indicate the significance levels at 1%, and 5%, respectively.

This pattern aligns with theoretical predictions from institutional economics. High-quality regulatory institutions enhance the credibility and signaling value of voluntary environmental certifications through several mechanisms. First, robust regulatory oversight reduces the likelihood of certification "greenwashing," ensuring that certified firms genuinely implement effective environmental management systems. This credibility enhancement proves particularly valuable in international markets, where information asymmetries between exporters and foreign buyers would otherwise create skepticism about environmental claims. Second, countries with superior regulatory quality typically possess well-functioning legal systems, transparent governance structures, and reliable contract enforcement mechanisms: complementary institutional assets that enable certified firms to

fully leverage their environmental credentials in commercial relationships. Third, strong regulatory institutions may foster broader environmental consciousness among domestic stakeholders, creating ecosystem conditions that support and reinforce the commercial value of environmental practices.

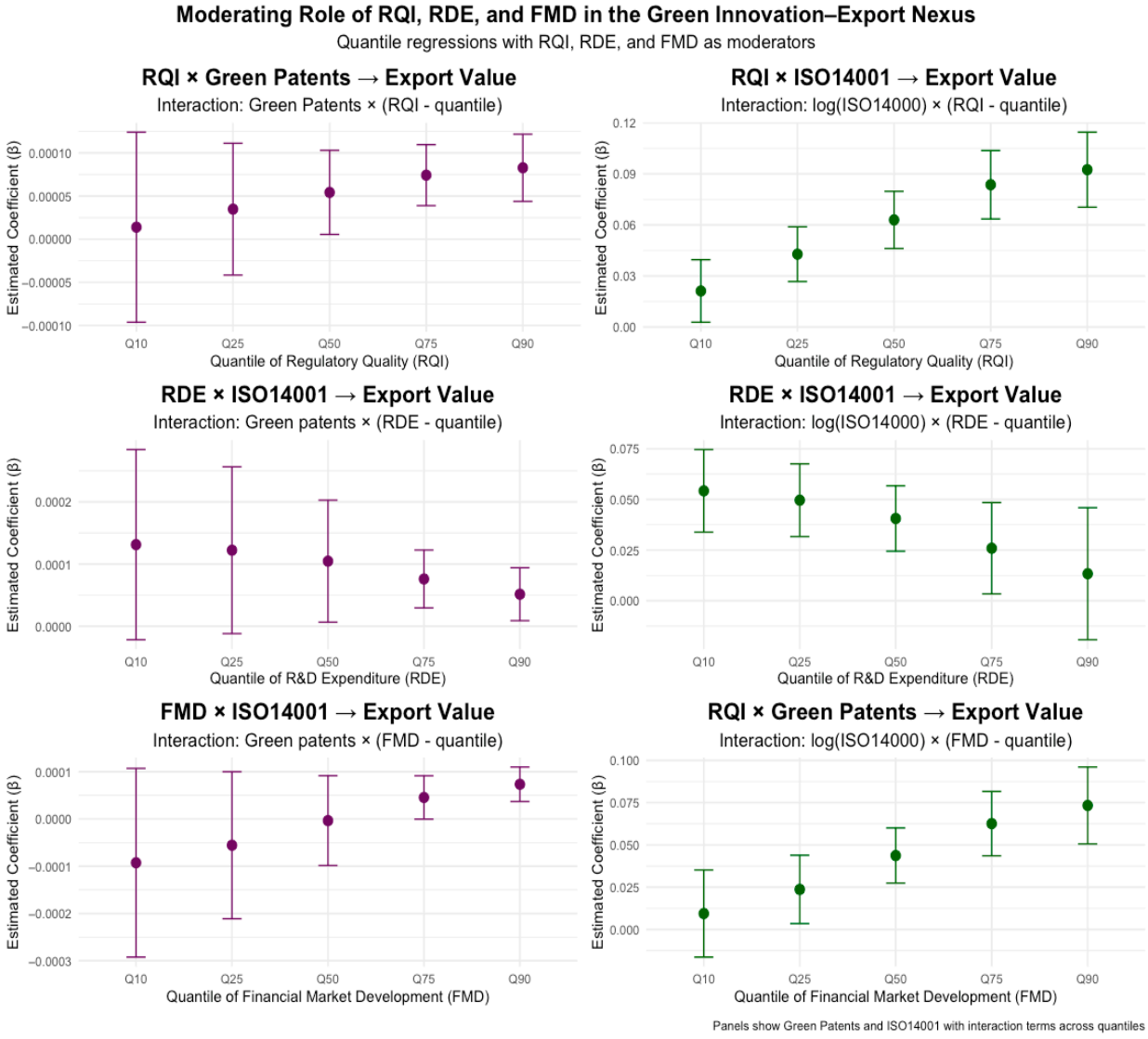

Figure 2. Moderating Effects of Institutional and Innovation Ecosystem Factors Across Export Performance Quantiles.

The absence of significant moderation for green patents warrants explanation. Unlike certification-based environmental practices, which depend heavily on institutional credibility for their market value, technological innovations possess inherent technical characteristics that international buyers can evaluate more directly. Environmental patents embody tangible technological solutions whose commercial value derives primarily from their functional performance rather than from institutional validation. Moreover, intellectual property protection for patents operates through specialized legal frameworks (international patent agreements, technology licensing regulations, and innovation-specific enforcement mechanisms) that may function somewhat independently of general regulatory quality. This suggests that while regulatory institutions strongly influence the effectiveness of certification-based environmental signals, they prove less critical for technology-based environmental advantages.

4.4.2. Research and Development Expenditure as Moderator

Table 9 presents marginal effects evaluated at different R&D expenditure quantiles. Contrary to innovation systems theory predictions, R&D expenditure demonstrates no significant moderating influence on either environmental practice. ISO14001's marginal effects range from 0.01333 (90th quantile) to 0.05420 (10th quantile), with most estimates failing to achieve statistical significance except at lower R&D quantiles. Green patents similarly exhibit no systematic variation in their export effects across R&D expenditure levels.

Table 9. Estimate results of marginal effects at different quantile of research and development expenditure.

Variables	10th	25th	50th	75th	90th
Green patents	0.00013	0.00012	0.00010	0.00007	0.00005
	(0.00015)	(0.00013)	(0.00009)	(0.00004)	(0.00004)
log(ISO14001)	0.05420 ***	0.04959 ***	0.04057 **	0.02590	0.01333
	(0.02037)	(0.01792)	(0.01614)	(0.02253)	(0.03255)
Control variables	Yes	Yes	Yes	Yes	Yes
Quantile of FMD (Q_q(FMD))	10th	25th	50th	75th	90th

***, and ** indicate the significance levels at 1%, and 5%, respectively.

This null finding, while initially unexpected, aligns with several theoretical perspectives and empirical observations from the innovation literature, revealing important insights about the specificity required for institutional moderators to be effective. The theoretical framework of absorptive capacity developed by Cohen and Levinthal [45] posits that organizations benefit from external knowledge only when they possess complementary internal capabilities to recognize, assimilate, and apply new information. Extending this logic to the national level, aggregate R&D expenditure may represent too diffuse a measure to capture the specific absorptive capacities required for environmental practices to generate export advantages. Countries may invest heavily in R&D while lacking the particular institutional configurations (environmental expertise, green technology commercialization pathways, or sustainability-oriented innovation networks) that would enable environmental practices to translate into competitive benefits.

Furthermore, Keller's [46] seminal work on international technology diffusion demonstrates that R&D investments generate substantial cross-border spillovers, with domestic investments often producing greater benefits for foreign countries than for the investing nation itself. This spillover dynamic proves particularly pronounced for environmental technologies, which exhibit strong public good characteristics that promote rapid international dissemination. Environmental innovations address global challenges (climate change, pollution, resource depletion) whose benefits transcend national boundaries, creating incentives for knowledge sharing and technology transfer. Consequently, a country's R&D expenditure may enhance environmental innovation globally without necessarily strengthening the relationship between its own environmental practices and export performance. The knowledge generated through domestic R&D diffuses internationally, benefiting competitors and reducing the proprietary advantages that might otherwise accrue to domestic firms from environmental practices.

Rennings [47] provides additional theoretical insight by distinguishing environmental innovation from conventional innovation, arguing that green technologies require specialized knowledge networks, regulatory frameworks, and institutional capabilities distinct from those supporting general innovation. Environmental innovations must simultaneously address technical performance criteria and environmental impact reduction: a dual objective requiring expertise that spans engineering, environmental science, regulatory

compliance, and market development. Aggregate R&D expenditure, which encompasses diverse research domains from biotechnology to information technology to materials science, fails to capture whether a country possesses the specific green technology capabilities relevant for environmental practice effectiveness. A country might rank highly in overall R&D intensity while lacking the particular environmental innovation competencies needed to amplify the export benefits of ISO14001 certification or environmental patents.

Most fundamentally, the nonsignificant moderating effect reflects what Jaffe et al. [48] term the "double externality problem" in environmental innovation. Green technologies face two distinct market failures: the traditional knowledge spillover problem that affects all innovations (reducing private appropriability of R&D investments) and the environmental externality problem specific to pollution control (limiting market rewards for environmental improvements). This dual externality structure means that environmental innovations systematically underperform commercially relative to their social value, and generic innovation capabilities (as proxied by aggregate R&D expenditure) prove insufficient to overcome these combined market failures. Rather, environmental innovations require targeted policy interventions specifically designed to address both externalities: intellectual property protections or subsidies to enhance appropriability, and environmental regulations or green procurement programs to create market demand for environmental improvements.

Our empirical findings thus reveal a critical insight about institutional complementarities in environmental policy. The effectiveness of environmental practices in generating export advantages depends not on general innovation capacity but on specific institutional conditions directly relevant to environmental management and green technology commercialization.

Regulatory quality matters because it enhances the credibility of environmental certifications and ensures enforcement of environmental standards. Financial market development matters because it facilitates capital-intensive environmental investments and enables firms to undertake complementary capability development. However, R&D expenditure, despite its obvious relevance to innovation broadly construed, operates at too aggregate a level and generates too many spillovers to effectively moderate the environment-export relationship. This finding carries important implications for policy design: countries cannot rely on increasing overall R&D expenditure to amplify the export benefits of environmental practices, but must instead develop targeted institutional capabilities (environmental technology commercialization programs, green finance instruments, sustainability expertise development) that directly support environmental practice effectiveness.

4.4.3. Financial Market Development as Moderator

Table 10 reveals that financial market development exerts a substantial positive moderating influence on ISO14001 certification, with marginal effects increasing from 0.00942 (10th quantile) to 0.07333 (90th quantile). This progression demonstrates that environmental management certifications generate their largest export benefits in countries with well-developed financial markets.

Table 10. Estimate results of marginal effects at different quantile of financial market development.

Variables					
Green patents	−0.00009	−0.00005	−0.00000	0.00004	0.00007 **
	(0.00019)	(0.00015)	(0.00009)	(0.00004)	(0.00003)
log(ISO14001)	0.00942	0.02369	0.04373 ***	0.06260 ***	0.07333 ***
	(0.02576)	(0.02020)	(0.01630)	(0.01903)	(0.02273)
Control variables	Yes	Yes	Yes	Yes	Yes
Quantile of FMD (Q_q(FMD))	10th	25th	50th	75th	90th

***, and ** indicate the significance levels at 1%, and 5%, respectively.

Well-developed financial markets facilitate the commercial exploitation of environmental certifications through several mechanisms. First, they reduce capital constraints that might otherwise prevent firms from making the substantial upfront investments required to implement and maintain ISO14001-compliant environmental management systems. Certification necessitates investments in monitoring equipment, training programs, process redesigns, and ongoing compliance verification: expenditures that generate returns only over extended periods. In countries with shallow financial markets, credit-constrained firms may forego certification despite its potential export benefits. Conversely, in countries with deep, liquid financial markets offering diverse financing instruments, firms can access capital for these investments at reasonable costs, enabling broader certification adoption and more effective implementation.

Second, sophisticated financial institutions possess superior capabilities for evaluating the commercial value of environmental management systems and incorporating environmental performance into credit assessments and investment decisions. Banks and investors in well-developed financial markets can better recognize certification as a signal of managerial quality, operational efficiency, and reduced regulatory risk, leading them to offer more favorable financing terms to certified firms. This creates stronger incentives for firms to pursue genuine environmental improvements rather than superficial compliance, enhancing the market value of certification.

Third, financial market development facilitates complementary investments that enable certified firms to fully leverage their environmental credentials in export markets. Access to diverse financing sources allows firms to simultaneously invest in environmental management systems, production technology upgrades, marketing capabilities, and international market development: complementary assets that amplify the export returns from certification. In less developed financial markets, firms may obtain certification but lack the capital for these complementary investments, limiting their ability to translate environmental credentials into export success.

As with regulatory quality, financial market development demonstrates no significant moderating effect on green patents. This consistent pattern across both institutional moderators reinforces the distinction between certification-based and technology-based environmental practices in their dependence on institutional context. While environmental management certifications require supportive institutional infrastructure to generate commercial value, technological innovations embody inherent capabilities that operate more independently of institutional conditions.

Overall, the moderating effects analysis reveals critical heterogeneity in how different environmental practices interact with institutional contexts. ISO14001 certification proves highly contingent on institutional quality, particularly financial market development and regulatory quality, with its export benefits materializing primarily in countries possessing well-developed supporting institutions. Green patents, conversely, generate export advantages through more direct, institution-independent pathways. These findings underscore the importance of coordinated policy approaches that align environmental practice promotion with institutional development, rather than treating environmental and institutional policies as independent domains.

4.5. Robustness Checks: Addressing Endogeneity Concerns

To address potential endogeneity from reverse causality and omitted variable bias, we employ instrumental variable (IV) estimation and System Generalized Method of Moments (GMM) alongside our baseline specification. Table 11 presents comparative results across these estimation strategies.

Table 11. Robustness Checks for Endogeneity.

Variables	Two-Way FE	Instrumental Variable	System GMM
$\log(\text{Export value})_{t-1}$			0.96718 ***
			(0.01615)
Green patents	0.00007 ***	0.00046	0.000004
	(0.00002)	(0.00033)	(0.00002)
log(ISO14001)	0.04435 **	0.35287	0.00738
	(0.02040)	(0.53482)	(0.01476)
log(Exchange rate)	−0.25570 ***	−0.56855	−0.00193
	(0.04091)	(0.51321)	(0.00291)
GDP growth of trade partners	1.13158 **	0.46373	0.48050
	(0.48025)	(0.74939)	(0.24647)
Trade barriers	0.02393	0.00013	−0.00355 *
	(0.02546)	(0.02428)	(0.00660)
Foreign direct investment	0.00044 ***	0.00081	−0.00002
	(0.00014)	(0.00115)	(0.00026)
Country FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Observations	330	240	570
First-stage F-stat (Green patents)		417.8398	
First-stage F-stat (log(ISO14001))		189.2446	
Sargan test			10.76672
(*p*-value)			(0.37598)
AR(1) test (*p*-value)			NaN
AR(2) test (*p*-value)			0.1759

Note: Column (1) shows baseline two-way fixed effects with Driscoll-Kraay standard errors. Column (2) presents instrumental variable estimation using lags 2–3 of EnvPatents and ISO14001 as instruments, with Arellano robust standard errors. Column (3) shows System GMM results with two-step robust standard errors. ***, **, and * indicate the significance levels at 1%, 5%, and 10%, respectively.

The baseline two-way fixed effects model with Driscoll-Kraay standard errors accounts for cross-sectional dependence and serial correlation. Country fixed effects control for time-invariant characteristics including institutional quality and technological capabilities, while time fixed effects capture common temporal shocks. Both green patents and ISO14001 certification demonstrate significant positive associations with export performance.

The instrumental variable (IV) approach addresses reverse causality (whereby successful exporters may possess greater resources to invest in environmental practices) using lags 2–3 of green patents and ISO14001 as instruments. First-stage F-statistics (417.84 for green patents; 189.24 for ISO14001) substantially exceed the conventional threshold of 10, confirming strong instruments. However, the instrumental variable estimates show both variables losing statistical significance, though point estimates remain positive. Standard errors increase dramatically, with ISO14001 rising from 0.020 to 0.534, reflecting substantially greater uncertainty when accounting for endogeneity. The sample reduces from 330 to 240 observations due to lag construction.

System GMM estimation addresses both endogeneity and dynamic panel bias. The lagged export coefficient of 0.967 reveals extreme persistence, with 96.7% of current exports explained by previous export levels. This extraordinary persistence reflects path-dependence from established trade relationships, sunk costs, and accumulated market knowledge documented in trade literature. Conditional on this lagged structure, both environmental variables lose significance, as high persistence leaves minimal variation for other factors to explain. Diagnostic tests show mixed validity: the Sargan test supports instrument exogeneity and the AR(2) test confirms no second-order autocorrelation, though the AR(1) test could not be computed due to numerical instability from extreme persistence.

These robustness checks reveal important qualifications to our baseline findings. The consistent loss of significance across IV and GMM specifications suggests that baseline

estimates likely represent upper bounds, potentially incorporating reverse causality. The maintained positive point estimates combined with inflated standard errors indicate considerable uncertainty rather than definitive rejection of positive effects. Alternatively, null results in dynamic specifications may reflect temporal mismatch between annual data and actual lag structures: environmental management implementation and green technology commercialization require multi-year horizons poorly captured by single-year lags. The extreme export persistence also indicates that structural factors and historical trajectories dominate short-run export determinants, limiting measurable impacts of any contemporaneous intervention. While direct effects weaken when addressing endogeneity, our primary contribution regarding institutional moderators examines conditional relationships potentially less susceptible to these concerns. These findings underscore the distinction between robust empirical associations and definitive causal effects, warranting cautious interpretation while suggesting directions for future quasi-experimental research employing stronger identification strategies.

5. Discussion

5.1. Theoretical Contributions and Comparison with Existing Literature

Our findings advance understanding of environmental practices and export performance through three principal contributions that complement and extend existing research. First, we demonstrate that environmental management systems (ISO14001) and green technological innovations (environmental patents) operate through fundamentally different mechanisms in their associations with export performance. ISO14001 certification exhibits strong institutional contingency, showing stronger correlations with exports in countries with high regulatory quality and well-developed financial markets. This finding aligns with institutional theory's legitimacy mechanisms while extending firm-level studies that documented positive effects without systematically examining institutional moderators. Our macro-level analysis reveals that this variation reflects systematic institutional differences rather than random firm heterogeneity. Countries with superior regulatory institutions provide the credibility infrastructure that makes certifications meaningful to international buyers, while weak institutions cannot effectively leverage voluntary environmental practices. Conversely, green patents demonstrate institution-independent associations, showing consistent relationships with exports across varying regulatory and financial contexts. This pattern supports the resource-based view's emphasis on technological capabilities as intrinsic competitive advantages but challenges simplistic Porter hypothesis interpretations, treating all environmental practices as equivalent innovation drivers. Our evidence suggests technological innovations embody capabilities that international markets evaluate directly, rendering them less dependent on institutional validation than certifications.

Second, our panel quantile regression reveals that environment-export relationships vary systematically across performance distributions. ISO14001 demonstrates relatively consistent positive associations across quantiles with slightly stronger point estimates at lower-to-middle levels, suggesting that environmental management systems correlate with export performance throughout export development stages. Green patents exhibit significant associations across most quantiles but lose significance at the highest levels, indicating potential saturation effects. These patterns extend existing literature by revealing continuous heterogeneity: environmental practices show different association patterns depending on performance position, with relationships shifting as countries advance through export development stages.

Third, our finding that regulatory quality and financial market development significantly moderate ISO14001's correlation with exports while R&D expenditure does not reveal critical institutional specificity. This challenges assumptions that general innovation

capacity uniformly enhances all innovation-related advantages. As the environmental innovation literature articulates, green technologies face double externality problems: knowledge spillovers reduce appropriability while environmental externalities limit market demand. Our macro-level evidence confirms that aggregate R&D capacity proves insufficient without targeted institutional interventions addressing both externalities.

However, our robustness checks employing instrumental variable estimation and System GMM reveal important qualifications to these contributions. When explicitly addressing potential endogeneity through IV approaches using lagged instruments, both green patents and ISO14001 lose statistical significance, though point estimates remain consistently positive. Similarly, System GMM estimation accounting for dynamic panel bias shows negligible effects once we control for the extreme persistence in export performance (lagged coefficient = 0.967). These findings suggest that our baseline results likely represent upper bounds on causal effects, potentially incorporating reverse causality whereby successful exporters subsequently invest more in environmental practices. Alternatively, the null results in dynamic specifications may reflect temporal mismatch between our annual data frequency and the multi-year horizons over which environmental management implementation and green technology commercialization actually generate trade benefits.

Importantly, while direct effects weaken substantially when addressing endogeneity, our theoretical framework regarding institutional moderators (which examines how contextual factors shape environment-export linkages) may prove more robust. Moderating relationships depend less on identifying precise causal magnitudes than on understanding conditional associations and how institutional configurations alter the translation of environmental practices into competitive advantages. The finding that regulatory quality and financial market development strengthen ISO14001's association with exports, while R&D expenditure does not, suggests that environmental practice effectiveness requires specific rather than generic institutional support. This theoretical insight remains valid whether the underlying direct effects represent causal impacts or complex bidirectional relationships.

5.2. Practical Implications and Policy Recommendations

Our quantile heterogeneity findings and differential institutional moderators yield policy implications that warrant careful interpretation given endogeneity concerns. Countries at lower export performance levels, where ISO14001 demonstrates stronger associations, may benefit from certification promotion through cost-sharing programs that reduce financial barriers to adoption. However, the significant regulatory quality moderation indicates that certification effectiveness depends on credible institutional frameworks. Countries should consider establishing independent oversight bodies with sufficient resources and technical expertise to conduct systematic auditing of certified firms, ensuring that results are publicly disclosed through accessible platforms that reduce information asymmetries for international buyers.

The significant moderation by financial market development indicates that well-developed financial systems enhance the extent to which environmental management certifications correlate with export performance. This suggests that countries with sophisticated financial infrastructure (including deep credit markets, developed bond markets, and efficient capital allocation mechanisms) create conditions enabling firms to access capital for the substantial investments certification requires. Policy could focus on developing broader financial system capacity that facilitates environmental investments, including credit facilities through development banks offering preferential financing terms and credit guarantee schemes providing coverage for financing to certified firms.

Countries at middle performance levels, where both ISO14001 and green patents show significant baseline associations, could create synergies through integrated support

mechanisms that incentivize simultaneous pursuit of certification and technological innovation. Specialized financing vehicles targeting environmental patent commercialization, combined with investment criteria requiring certified environmental management systems, might exploit complementarities between certification signaling and patent technological capabilities. Financial system development priorities should include establishing diverse capital sources for environmental investments, with both debt and equity instruments supporting firms at different stages of environmental practice adoption and innovation.

However, these policy recommendations require substantial qualification given our robustness check findings. The loss of statistical significance in IV and GMM specifications suggests that simple promotion of environmental practices may not generate the export benefits our baseline results suggest. Rather, environmental practices appear embedded in complex causal webs involving bidirectional relationships with export performance and long-term institutional development. Effective policy likely requires patient, sustained institutional building in regulatory quality and financial market development rather than short-term interventions promoting specific practices. The extreme export persistence documented in our GMM results (0.967) further indicates that any policy intervention faces significant barriers to generating measurable short-run impacts on aggregate export performance.

Implementation should therefore proceed cautiously, recognizing uncertainty about causal mechanisms while leveraging insights about institutional complementarities. Initial phases might focus on establishing credible regulatory oversight and developing financial system capacity rather than aggressively promoting certification adoption. Intermediate phases could target measurable improvements in regulatory quality indices and financial system sophistication while carefully evaluating whether firms adopting environmental practices actually experience export gains. Longer-term objectives should aim for institutional quality levels supporting genuine competitive advantages from environmental practices, with realistic expectations about timeline and effect magnitudes based on our robustness check findings rather than baseline correlations.

6. Conclusions

This study investigated how institutional and innovation ecosystem factors moderate the relationship between green practices and export performance using panel data from 30 European countries for the period 2012–2022. Employing panel quantile regression alongside instrumental variable estimation and System GMM to address endogeneity, we identified critical institutional contingencies and performance-dependent heterogeneity in environment-export associations.

Our findings establish three principal contributions. First, ISO14001 certification and environmental patents demonstrate fundamentally different patterns: certifications exhibit strong institutional contingency, showing stronger correlations in countries with high regulatory quality and well-developed financial markets, while patents demonstrate institution-independent associations. Second, environmental practice benefits vary systematically across export performance distributions, with ISO14001 showing consistent positive associations throughout while green patents exhibit diminishing associations at the highest performance levels. Third, regulatory quality and financial market development significantly moderate certification's association with exports, while R&D expenditure shows no moderation, indicating that environmental practices require targeted institutional support rather than generic innovation infrastructure.

However, robustness checks reveal important qualifications. When explicitly addressing reverse causality through instrumental variable approaches, both green patents and ISO14001 lose statistical significance, though point estimates remain consistently positive. System GMM estimation reveals extreme export persistence (lagged coefficient = 0.967),

leaving minimal variation for contemporaneous variables to explain. These findings suggest that baseline results likely represent upper bounds, potentially incorporating bidirectional dynamics whereby successful exporters subsequently invest more in environmental practices. The relationships may also operate through longer-term mechanisms poorly captured by annual data, as environmental management implementation requires multi-year horizons to generate measurable benefits.

Several limitations warrant acknowledgment and suggest directions for future research. First, while our approaches address time-invariant heterogeneity, we cannot definitively establish causality despite robustness checks. The extremely high export persistence suggests that structural factors dominate short-run determinants. Future quasi-experimental research employing difference-in-differences around policy reforms or regression discontinuity designs would strengthen causal inference. Second, our measurement of green innovation through environmental patents does not encompass eco-efficient processes, green digitalization, or circular economy practices. Future research employing comprehensive eco-innovation indicators would provide a more complete understanding. Third, our focus on European countries limits external validity, as these nations generally possess more developed institutions than emerging economies. Cross-regional comparative research would illuminate alternative pathways in different institutional contexts.

Methodologically, fuzzy-set Qualitative Comparative Analysis (fsQCA) [49,50] could investigate how different combinations of environmental practices, institutional factors, and country characteristics jointly produce export success, revealing equifinal pathways and configurational relationships our regression approach cannot capture. This approach, which has proven particularly valuable for analyzing complex causality in organizational and international business research [51], would illuminate whether multiple distinct configurations generate success, whether institutional conditions substitute for one another, and whether factors promoting high performance differ from those preventing low performance.

Despite limitations, our findings contribute robust evidence that environmental practices show consistent positive associations with export competitiveness across multiple specifications. Our primary contribution (documenting how regulatory quality and financial market development moderate environment-export relationships) provides insights into institutional complementarities potentially less sensitive to endogeneity concerns, as moderating relationships examine conditional associations rather than requiring precise causal identification. These findings underscore the distinction between robust empirical associations and definitive causal effects. The baseline correlations we document appear economically meaningful, yet establishing causality requires stronger identification than observational panel data can provide. The challenge lies not in whether environmental practices and export performance relate positively but in understanding the causal mechanisms, temporal dynamics, and institutional conditions through which these relationships operate.

Author Contributions: Conceptualization, C.K.; methodology, C.K.; software, S.C.; validation, C.K. and S.C.; formal analysis, C.K.; investigation, C.K.; resources, C.K.; data curation, S.C.; writing—original draft preparation, C.K.; writing—review and editing, C.K.; visualization, S.C.; supervision, C.K.; project administration, C.K.; funding acquisition, C.K. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by Chiang Mai University.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

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