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Article

Enhancing Green Innovation Through National Intellectual Capital: The Role of Institutional Quality in Asia–Pacific Economies

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Abstract: The impact of intellectual capital on green innovation has been extensively studied at the firm level. However, the influence of moderating factors on this dynamic at the national level remains underexplored in previous studies. This study examines the role of institutional quality in moderating the relationship between national intellectual capital and green innovation across seventeen Asia–Pacific economies over the last twenty years, starting from 2000. Various techniques are employed to account for cross-sectional dependence and slope homogeneity in panel data analysis, enabling the examination of this relationship over the long and short term. The study also considers the marginal effects of national intellectual capital on green innovation at different degrees of institutional quality. Overall findings indicate that increasing national intellectual capital and institutional quality increases green innovation. Interestingly, the effects of national intellectual capital on green innovation intensify with a greater degree of institutional quality. We also find that enhancing economic growth and the efficient exploitation of natural resources appear to stimulate green innovation in Asia–Pacific economies. Findings imply that policies to improve green innovation should align with traditional economic growth strategies and effectively leverage intangible resources, particularly national intellectual capital. This unique empirical study examines the moderating role of institutional quality in the national intellectual capital–green innovation nexus in Asia–Pacific economies.



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Keywords: national intellectual capital; institutional quality; green innovation; Asia–Pacific economies

1. Introduction

Amidst escalating global environmental degradation, resource depletion, and economic uncertainties, significant challenges emerge in energy conservation, the transition to green energy, and pollution mitigation (Kahia et al., 2024). Green innovation has been recognized as a transformative approach to addressing these challenges and enhancing the sustainability of production processes (Ahakwa et al., 2024). However, economic contractions resulting from environmental regulations may generate externalities that hinder further innovation, thereby limiting the communal benefits of green innovation (Coussa et al., 2024). Given its growing importance, numerous studies have explored the factors influencing green innovation. It is widely acknowledged that the benefits of green innovation can be fully realized only when complemented by advancements in human capital (Alfalih & Hadj, 2024), which constitutes a fundamental component of national intellectual capital.

National intellectual capital shapes national wealth, competitiveness, and the informal economy. While prior research has provided valuable insights into the relationship between national intellectual capital and economic growth (Vo & Tran, 2024), significant gaps remain in the literature. First, most studies have concentrated on the influence of intellectual capital on green innovation at the firm level (Asiaei et al., 2023; Shahbaz et al., 2024), with relatively limited attention given to its impact at the national level. Second, existing research on the intellectual capital–green innovation nexus is predominantly grounded in theoretical frameworks suggesting that intellectual capital influences green innovation either directly or indirectly through mechanisms such as co-creational capital (Almansour, 2024), innovative work behavior (Shahbaz et al., 2024), and resource allocation (Wang et al., 2023). Truong et al. (2024) affirm that the positive effect of intellectual capital on green innovation is reinforced by strong government support. Given that national intellectual capital is a multidimensional construct encompassing various interrelations (Vo et al., 2024), it is imperative to examine such moderating effects. National intellectual capital often manifests in forms such as educated labor, innovation infrastructure, and knowledge networks (Vo & Tran, 2024). Institutional quality ensures that these resources are allocated efficiently, minimizing bureaucratic hurdles and rent-seeking behaviors that might otherwise distort innovation incentives (Yang et al., 2024). The effectiveness of national intellectual capital in driving green innovation may depend on the quality of a country’s institutional environment (T. P. K. Tran, 2024). Strong institutions can reduce transaction costs, enhance investor confidence, and facilitate the efficient implementation of knowledge-based initiatives, suggesting a potential moderating role that warrants further examination. Notably, previous research in this area has largely overlooked the role of institutional quality. However, considering that the effectiveness of national intellectual capital is contingent upon the level of institutional quality (T. P. K. Tran, 2024), it is crucial to assess the moderating influence of institutional quality on the relationship between national intellectual capital and green innovation. This perspective suggests that institutional quality may either enhance or diminish the impact of national intellectual capital on green innovation. Third, green innovation at the national level is a complex and multifaceted process, and an exclusive focus on short-term outcomes may obscure the enduring influence of national intellectual capital on green innovation. Prior studies, such as those by Wang et al. (2023), have identified key drivers of green innovation, emphasizing the necessity of considering a broad range of factors to fully capture their intricate dynamics, cumulative effects, institutional influences, and implications for sustainable economic transitions. Consequently, there is an urgent need to expand research on the relationship between national intellectual capital and green innovation by incorporating its long-term cumulative effects and dynamic nature.

Despite the Asia–Pacific region’s significant contribution to the global economy—accounting for approximately 40 percent of global economic growth (IMF, 2023)—it has been largely overlooked in prior studies. This region comprises diverse economies at varying stages of development and has undergone substantial transformations over time. Expanding research beyond short-term analyses is essential to comprehensively understand the lasting effects of national intellectual capital on green innovation. Given the rapid evolution of intangible assets, including national intellectual capital, and the increasing interconnectedness of the global economy, adopting a long-term perspective is crucial for effective policy formulation and strategic planning. This study seeks to investigate the long-term impact of national intellectual capital on green innovation through the lens of institutional quality in the Asia–Pacific region, providing valuable insights for policymakers, businesses, and academics.

Given the critical role of green innovation in the economies of the Asia–Pacific region, this study makes several contributions to the existing literature on intellectual capital and

innovation. First, this unique study examines the impact of national intellectual capital on green innovation in Asia–Pacific countries. Second, this research introduces a novel perspective by investigating the moderating effect of institutional quality on the relationship between national intellectual capital and green innovation at the national level. The extent to which institutional quality enhances or diminishes the impact of national intellectual capital on green innovation remains an open question in the existing literature. Addressing this gap is crucial, as policymakers and government bodies require empirical evidence on how institutional quality influences the effectiveness of national intellectual capital in driving green innovation. Third, this study emphasizes the long-term relationship between national intellectual capital and green innovation by employing dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS) estimation techniques. Furthermore, multiple robustness checks are conducted to validate the empirical findings and ensure the reliability of the results.

The remainder of this paper is structured as follows: Section 2 provides a comprehensive review of the relevant literature. Section 3 outlines the data sources and research methodology. Section 4 presents the empirical findings and their discussion, while Section 5 concludes with key insights and policy recommendations.

2. Literature Review

The literature review starts by exploring this study's theoretical foundation. Next, it reviews previous research on the relationship between national intellectual capital, institutions, and green innovation.

2.1. Asia–Pacific Region's Innovation-Driven Economic Growth

Over the past two decades, the Asia–Pacific region has witnessed significant economic progress, with notable advancements in information and communication technology (ICT) development, STEM education, technology transfer, and the rise of vibrant start-up ecosystems. Countries like China, Japan, South Korea, and Singapore have been at the forefront of ICT innovation and digital transformation, fostering robust ecosystems for technology-driven growth. The region has also seen an increase in cross-border cooperation, particularly in technology transfer, innovation partnerships, and inclusive green-tech initiatives, as part of a collective drive towards sustainable development (Dewasiri, 2024). Cross-border cooperation, particularly through initiatives like the APEC Policy Partnership on Science, Technology and Innovation (PPSTI), facilitated collaborative research and technology transfer, contributing to regional economic growth (Canton, 2021). Studies suggest that the key priority areas for strengthening innovation potential in the Asian economy include enhancing public–private partnerships, fostering STEM education and research collaboration, advancing digital infrastructure, and promoting sustainable green-tech innovations (Clarke et al., 2017).

In particular, collaboration between the business, public, and scientific research sectors has been integral to shaping a more innovation-driven economy. For instance, the Asia–Pacific Program of Education for All (APPEAL) emphasized the role of home and community in lifelong learning, recognizing the need for education and training in both formal and non-formal sectors (Wirawan et al., 2025). Business models for human capital development, a crucial component of national intellectual capital (Vo & Tran, 2024), often leverage public–private partnerships, collaborative research initiatives, and continuous professional development programs. Additionally, the Asian Development Bank's report on education, skill training, and lifelong learning in the era of technological revolution underscores the importance of equipping workers with higher and different skills to adapt to accelerating technical and market changes (Qian & Zhang, 2024). These efforts collectively contributed

to the region's innovation-driven economic growth, highlighting the importance of the role of intangible assets, such as national intellectual capital, and institutional quality, in fostering sustainable development. Figure 1 shows green innovation of selected countries in the Asia-Pacific region during the period 2000–2020. These visualizations illustrate the diversity in green innovation trajectories across countries with differing institutional environments and intellectual capital development.

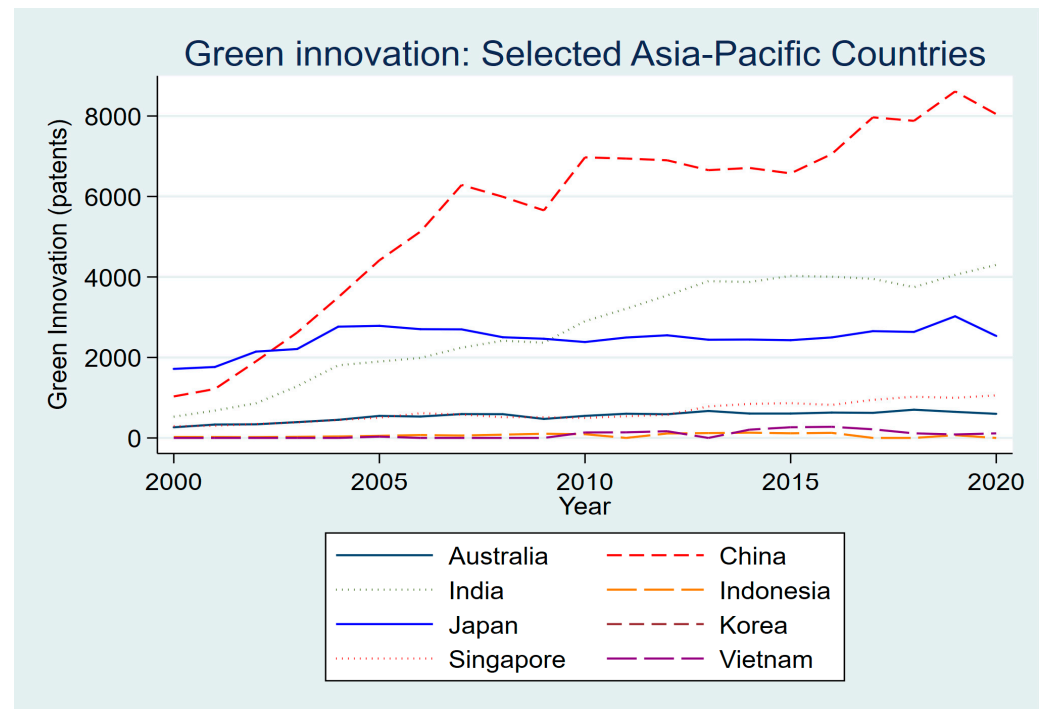


Figure 1. Green innovation in selected Asia-Pacific countries from 2000 to 2020.

2.2. Theoretical Foundation

The resource-based theory (Barney, 1996) asserts that a firm or nation's distinctive resources and capabilities are the foundation for sustained competitive advantage and long-term economic growth. Within national intellectual capital, this theory highlights the significance of intangible assets—such as human capital, knowledge, and innovation capabilities—as key drivers of sustainable innovation (Vo & Tran, 2024). National intellectual capital plays a pivotal role in fostering green innovation by facilitating the development of environmentally friendly technologies and sustainable practices (Vo et al., 2024). From this perspective, countries with abundant intellectual resources are more likely to achieve higher levels of green innovation, leveraging their intellectual capital to create sustainable competitive advantages and promote eco-friendly economic growth (Lin, 2018). Hence, we propose the following hypothesis:

H1. *National intellectual capital has a positive effect on green innovation.*

Institutional theory further strengthens this view by highlighting how institutional structures—such as legal systems, governance mechanisms, and regulatory frameworks—influence national and organizational behavior, particularly in the area of innovation (Yang et al., 2024). High-quality institutions, marked by robust legal safeguards, clearly defined property rights, and efficient regulatory systems, play a pivotal role in advancing green innovation by reducing uncertainty and boosting investor confidence (Tebaldi & Elmslie, 2013). These institutions shape the incentives and capacities of key

stakeholders in the innovation ecosystem, including firms, academic institutions, and public agencies. Effective governance encourages collaboration, secures intellectual property, and supports sustainable, long-term innovation strategies. Consistent with the existing body of literature, the following hypothesis has been established:

H2. *Institutional quality has a positive effect on green innovation.*

Moreover, institutions play a crucial role in setting regulatory standards and frameworks that drive industries and firms toward the adoption of green technologies and the implementation of sustainable practices (Shah & Asghar, 2024). According to institutional theory, high-quality institutions enhance the positive influence of national intellectual capital on green innovation. This occurs as robust institutional environments help reduce transaction costs, minimize uncertainties, and promote the widespread adoption of green technologies (T. P. K. Tran, 2024). They also reinforce the innovation ecosystem by protecting intellectual property rights, upholding environmental regulations, and fostering collaboration, thereby enabling intellectual capital to contribute more effectively to green innovation. Thus, institutional quality functions as a moderating factor, reinforcing the role of national intellectual capital in driving green innovation. While national intellectual capital provides the intellectual assets and expertise required to advance green technologies (Vairinhos et al., 2019), institutional quality ensures that regulatory frameworks align economic growth with environmental sustainability. The integration of these theoretical perspectives underscores the necessity of combining national intellectual capital with institutional quality to achieve sustainable development through green innovation. Therefore, this study proposes the following hypothesis:

H3. *Institutional quality positively moderates the relationship between national intellectual capital and green innovation.*

2.3. Impact of National Intellectual Capital and Institutional on Green Innovation

This section concisely overviews pertinent empirical research examining the connections between national intellectual capital, institutions, and green innovation. The following discussion addresses each of these linkages sequentially.

2.3.1. National Intellectual Capital and Green Innovation

National intellectual capital—the collective knowledge, skills, expertise, and innovation capacity within a country—serves as a critical resource for advancing green innovation at the national level (Lin, 2018). Grounded in resource-based theory, national intellectual capital is recognized as a valuable and inimitable asset that provides countries with a sustainable competitive advantage (Vo & Tran, 2024).

A key component of national intellectual capital is human capital, which encompasses individuals' education, skills, and knowledge within a country. Highly skilled human capital is pivotal in green innovation by driving research and development (R&D) in green technologies, environmental sciences, and sustainable practices (Hina et al., 2024; Zhou et al., 2023). Countries with a strong human capital base are likelier to have a well-educated workforce capable of identifying and addressing environmental challenges, fostering a culture of innovation aimed at sustainability (Danta & Rath, 2024). For instance, educated scientists, engineers, and entrepreneurs can leverage their expertise to develop eco-friendly technologies and systems, promoting green innovation and contributing to a sustainable economy (Pham & Pham, 2023). Beyond human capital, structural capital—comprising institutional frameworks, technological infrastructure, and knowledge management systems—also plays a crucial role in fostering sustainable competitive advan-

tages and promoting environmentally friendly economic growth (X. Zhao & Qian, 2024). Recent studies (Gao et al., 2023; Y. Han et al., 2024) have highlighted the significance of digital technology in facilitating green innovation. As digital technologies become increasingly prevalent, data-driven processes enable the collection, integration, and analysis of information and the dissemination and exchange of knowledge, all of which contribute to corporate green innovation initiatives (F. Han & Mao, 2024). For example, X. Zhao and Qian (2024) analyzed panel data from 30 Chinese regions from 2003 to 2019. They found that intangible assets, mainly digital technology, significantly enhance green innovation performance, a conclusion reinforced by robustness tests. Additionally, relational capital—encompassing a nation's networks, partnerships, and connections with external stakeholders such as international organizations, foreign investors, and environmental advocacy groups—facilitates the diffusion of green knowledge and practices (Y. Zhao et al., 2024). Through collaborative networks and global partnerships, countries can gain access to advanced green technologies, exchange best practices, and benefit from the experiences of other nations that have successfully implemented green innovations (X. Li et al., 2024). This cross-border exchange of ideas and technological advancements enhances a country's capacity for green innovation (B. Xu & Lin, 2024), positioning national intellectual capital as a key driver of sustainable development.

2.3.2. Institutional Quality and Green Innovation

Institutional quality plays a crucial role in fostering green innovation. Porter (1991) argues that well-designed environmental regulations can catalyze entrepreneurial technological innovation. Governments can incentivize firms to engage in green innovation by establishing stringent environmental targets, offering financial incentives, and imposing penalties for non-compliance (Chen et al., 2024). Empirical studies have consistently affirmed the positive impact of environmental regulations on green innovation, with evidence drawn from various national contexts.

Focusing on China, L. Xu et al. (2023) distinguish between clean production standards and pollution emission standards, highlighting their asymmetric effects on green innovation. Similarly, Huo et al. (2024) investigate the impact of climate policy uncertainty on corporate green innovation performance using a sample of A-share listed companies in Shanghai and Shenzhen from 2007 to 2020. Their study further examines the moderating role of organizational inertia and the combined moderating effects of managerial openness, risk-taking propensity, and organizational inertia. The findings indicate that climate policy uncertainty positively influences corporate green innovation performance, suggesting that regulatory ambiguity may encourage firms to develop adaptive and forward-looking innovation strategies. Beyond direct regulatory measures, governments can promote green innovation by cultivating a supportive innovation ecosystem (Wang et al., 2023). L. Li et al. (2022) argue that implementing pilot policies in intellectual property and innovative cities can enhance the broader innovation environment. By fostering the concentration of key innovation drivers—such as human capital, financial resources, and advanced technologies—these policies contribute to advancing green innovation.

2.3.3. Moderating Role of Institutional Quality

National intellectual capital is pivotal in fostering innovation, mainly green innovation. Therefore, it is essential to emphasize the moderating role of institutional quality in the relationship between national intellectual capital and green innovation. National intellectual capital can drive transformative changes across industries by providing the knowledge base, innovative capacity, and collaborative networks necessary for developing environmentally sustainable technologies and practices (Asiaei et al., 2023). However, the extent

to which national intellectual capital translates into green innovation outcomes depends significantly on the broader institutional environment (Ahakwa et al., 2024). Institutional quality may be a critical moderator in this relationship, reflecting the effectiveness of legal frameworks, governance, and regulatory standards. High institutional quality creates a conducive environment for green innovation by establishing clear environmental standards, protecting intellectual property rights, and fostering transparency in business practices (Almansour, 2024). When national intellectual capital interacts with robust institutions, the synergies are amplified; human capital benefits from skill-enhancing policies, structural capital thrives under stable governance, and relational capital flourishes in predictable regulatory landscapes (Cheng et al., 2023). For instance, effective institutions may incentivize organizations to allocate intellectual resources toward green innovation by providing subsidies, tax incentives, or grants for sustainable projects (Velez-Calle et al., 2024). Thus, institutional quality can enhance the efficiency and effectiveness of national intellectual capital in fostering green innovation. Conversely, in contexts with weak institutional frameworks, the potential of national intellectual capital to drive green innovation may be hindered (Chien et al., 2024). Poor governance, corruption, or lack of regulatory enforcement can create uncertainties that deter investments in innovative and sustainable practices. Even with high national intellectual capital, firms may prioritize short-term economic gains over long-term green initiatives without institutional pressure or support (Danta & Rath, 2024). Moreover, inadequate protection of intellectual property rights could discourage collaboration and knowledge sharing, critical components of national intellectual capital, further limiting its impact on green innovation (Chen et al., 2024).

Given these dynamics, it is plausible to argue that the relationship between national intellectual capital and green innovation is contingent upon institutional quality. When institutional quality is high, the positive effects of national intellectual capital on green innovation are likely to be more pronounced (Danta & Rath, 2024). However, in the presence of weak institutions, the transformative potential of national intellectual capital may not be fully realized (Vo et al., 2024). Therefore, this study hypothesizes that institutional quality moderates the relationship between national intellectual capital and green innovation, such that the relationship is stronger under conditions of high institutional quality.

3. Research Methodology

The research model is developed first to analyze the effect of national intellectual capital and institutional quality on green innovation. Next, the data sources, details of variables used in the research model, and descriptive statistics of data are discussed.

3.1. Research Model

This paper examines the impacts of national intellectual capital and institutional quality on green innovation. This study also investigates whether the effects of national intellectual capital on green innovation change at different levels of institutional quality. The panel DOLS and FMOLS estimation methods have been used on 17 Asia-Pacific economies for the past two decades since 2000. The following general equation is used:

$$GIN_{it} = \beta_0 + \beta_1 NIC_{it} + \beta_2 INS_{it} + \beta_3 X_{it} + \varepsilon_{it} \quad (1)$$

In Equation (1), i and t represent the country and period, respectively. GIN denotes green innovation, NIC stands for national intellectual capital, and INS represents institutional quality.

Building upon the frameworks established in previous research (T. P.-K. Tran et al., 2022; Vo & Tran, 2022), this study employs a composite national intellectual capital index comprising three key components: human capital, structural capital, and relational capital.

Institutional quality is assessed through principal component analysis (PCA), calculated as follows:

$$INS = \sum_{i=1}^n \omega_i IQ_i$$

where ω_i represents the component loadings or weights, and IQ_i denotes the institutional quality components, which synthesize five critical governance-related indicators: business freedom, regulatory quality, investment freedom, government effectiveness, and the rule of law.

The model also incorporates a set of control variables (denoted as X), including economic growth—measured as the natural logarithm of gross domestic product (GDP), the abundance of natural resources (NRR), and renewable energy consumption (REC). The selection of these variables is grounded in empirical findings from recent studies, notably those by [Alfalih and Hadj \(2024\)](#) and [Wang et al. \(2023\)](#). Table 1 provides detailed descriptions and measurement approaches for all variables used in the analysis.

Table 1. Description of variables and measurements.

No.	Variable	Measurement	Abbreviation	Source
Dependent variable				
1	Green innovation	Natural logarithm of the total number of environment-related patent applications	GIN	OECD
Independent variables				
2	National intellectual capital	National intellectual capital index	NIC	Vo and Tran (2022) and WDI WGI and Heritage.org
3	Institutional quality	Institutional quality index	INS	
Control variables				
4	Economic growth	Natural logarithm of GDP (constant 2015 US)	LGDP	WDI
5	Natural resource abundance	Natural resource rent (percent of GDP)	NRR	WDI
6	Renewable energy consumption	Renewable energy consumption (percent of total energy consumption)	REC	WDI

We examine whether institutional quality moderates the relationship between national intellectual capital and green innovation. The model includes an interaction term between national intellectual capital and institutional quality to capture this potential moderating effect. The rationale behind this interaction term is that the impact of national intellectual capital on macroeconomic outcomes, such as green innovation, may vary depending on the level of institutional quality ([T. P.-K. Tran et al., 2022](#)).

$$GIN_{it} = \beta_0 + \beta_1 NIC_{it} + \beta_2 INS_{it} + \beta_3 NIC_{it} \times INS_{it} + \beta_4 X_{it} + \varepsilon_{it} \quad (2)$$

This study captures the marginal effect of national intellectual capital on green innovation through the interaction term by taking the partial derivative of Equation (2) with respect to national intellectual capital (NIC), written as follows:

$$\frac{\partial GIN_{it}}{\partial NIC_{it}} = \beta_1 + \beta_3 INS_{it} \quad (3)$$

From Equation (3), the signs of the estimated coefficients, β_1 and β_3 , are analyzed. A positive sign for both β_1 and β_3 suggests that higher levels of national intellectual capital and improved institutional quality positively influence green innovation. In contrast, if β_1 and β_3 exhibit opposite signs, this implies a threshold effect, indicating that the impact of national intellectual capital on green innovation is contingent on the level of institutional quality. For example, supposing β_1 is positive and β_3 is negative, then the marginal effect of national intellectual capital is positive at lower levels of institutional quality but diminishes or becomes negative at higher levels. Thus, evaluating the marginal effects across the sample is essential for a comprehensive understanding.

The literature review highlights various methodologies for analyzing relationships in dynamic panel data. While fixed and random effects models are widely used in panel data analysis, they do not account for integration and cointegration properties, which are critical for examining long-term dynamics (Pesaran, 2021). The generalized method of moments (GMMs) is another common approach, but it similarly overlooks integration and cointegration, potentially leading to unreliable results (Osuntuyi & Lean, 2022).

This study employs a dynamic panel dataset comprising 17 Asian countries, where endogeneity and heterogeneity are significant concerns (Beck et al., 2000). To address these issues, methodologies that account for endogeneity and heterogeneity are deemed most appropriate. Specifically, this research employs fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) to estimate long-term relationships among cointegrated variables. FMOLS, a non-parametric approach, corrects for serial correlation in variables integrated of order one (I(1)) (Phillips & Hansen, 1990), providing robust estimates even with limited sample sizes and ensuring the validity of long-term coefficients. DOLS, a parametric method, incorporates lags and leads to address correlations among variables, regardless of their integration order (I(0) or I(1)) and cointegration status (Stock & Watson, 1996). Due to its dynamic structure, this approach mitigates endogeneity concerns and yields unbiased cointegrating coefficients (Inagaki, 2010).

3.2. Data Sources

This study covers 17 Asia–Pacific countries from 2000 to 2020. Table 2 presents a list of economies.

Table 2. List of countries included in the analysis.

Australia	Japan	Philippines
Bangladesh	Korea	Singapore
Cambodia	Malaysia	Sri Lanka
China	Mongolia	Thailand
India	New Zealand	Vietnam
Indonesia	Pakistan	

The data for green innovation are sourced from the OECD, while the national intellectual capital data are derived from the World Development Indicators (WDI). Information on institutional quality is obtained from the World Bank’s Worldwide Governance Indicators (WGI) and Heritage.org.

Table 3 presents the descriptive statistics for all variables included in the analysis. The values for green innovation range from a minimum of 0.000 to a maximum of 9.060, with a mean score of 4.517 across the Asia–Pacific economies. National intellectual capital exhibits a mean value of 0.465, with a standard deviation of 0.244, and ranges from 0.058 to 1.051. The relatively large standard deviations observed for these variables indicate considerable dispersion around their mean values, reflecting significant variability within the dataset.

Table 3. Descriptive statistics.

	Observations	Mean	Std. Dev.	Min	Max
GIN	357	4.517	2.809	0.000	9.060
Δ GIN	340	0.057	1.088	−5.117	5.327
NIC	357	0.465	0.244	0.058	1.051
Δ NIC	340	0.014	0.019	−0.053	0.215
INS	357	5.88×10^{-9}	0.977	−2.300	2.341
Δ INS	340	0.040	0.598	−2.130	2.360
LGDP	357	26.417	1.771	22.062	30.313
Δ LGDP	340	0.046	0.032	−0.100	0.159
NRR	357	0.037	0.053	1.69×10^{-6}	0.422
Δ NRR	340	−0.001	0.020	−0.199	0.121
REC	357	0.262	0.208	0.003	0.816
Δ REC	340	−0.004	0.014	−0.089	0.040
NIC \times INS	357	0.040	0.498	−1.688	1.492
Δ NIC \times INS	340	0.033	0.283	−1.008	1.752

4. Empirical Results and Discussions

4.1. The Cross-Sectional Dependence Test

Cross-sectional dependence is a common issue in panel data estimation and can result in inefficient estimates. To address this, the study uses the [Pesaran \(2004\)](#) CD test to assess cross-sectional dependence. The results, presented in Table 4, show that the hypothesis of cross-sectional independence is not supported at the 1% significance level. This finding suggests that conducting the panel unit root test using the first difference of the variables yields more reliable results.

Table 4. Cross-section dependence test results.

Variables	GIN	NIC	INS	LGDP	NRR	REC	NIC \times INS
CD test	24.744 ***	49.509 ***	11.380 ***	52.064 ***	18.833 ***	15.240 ***	14.073 ***
<i>p</i> -value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: *** significant at the 1 percent level.

4.2. Slope Homogeneity Test

[Breitung \(2001\)](#) argues that neglecting cross-sectional dependence and presuming panel homogeneity may lead to biased outcomes in panel heterogeneity. The slope homogeneity test developed by [Pesaran and Yamagata \(2008\)](#) is utilized to address this concern. As illustrated in Table 5, the null hypothesis of slope homogeneity is rejected, confirming the presence of slope heterogeneity in the dataset under investigation.

Table 5. Slope homogeneity test results.

	Slope Homogeneity Test	
	Δ	Δ adj
Equation (1)	−11.314 *** (0.000)	−3.411 *** (0.000)
Equation (2)	−11.314 *** (0.000)	−3.411 *** (0.000)

Notes: *** significant at 1% level.

4.3. Panel Unit Root Test

A panel unit root test is conducted to examine the stationarity properties of the variables under investigation. Specifically, this study utilizes the panel unit root test proposed by Pesaran (2003) to determine the stationarity and integration order of the variables. As presented in Table 6, the results reveal that all variables attain stationarity at the first difference. This finding suggests a potential long-term, cointegrating relationship among the analyzed variables.

Table 6. Panel unit root test results.

Variables	Level		First Difference		Order of Integration
	Constant (1)	Constant and Trend (2)	Constant (3)	Constant and Trend (4)	
GIN	−0.754 (0.225)	−0.821 (0.206)	−6.673 *** (0.000)	−6.104 *** (0.000)	I(1)
NIC	−0.742 (0.229)	0.254 (0.600)	−4.597 *** (0.000)	−2.919 *** (0.002)	I(1)
INS	−0.298 (0.383)	0.235 (0.593)	−5.660 *** (0.000)	−3.048 *** (0.001)	I(1)
LGDP	−0.433 (0.332)	3.890 (1.000)	−3.967 *** (0.000)	−3.351 *** (0.000)	I(1)
NRR	0.541 (0.706)	−0.537 (0.296)	−5.650 *** (0.000)	−3.644 *** (0.000)	I(1)
REC	0.958 (0.831)	4.430 (1.000)	−2.103 ** (0.018)	−2.068 ** (0.019)	I(1)
NIC × INS	−0.315 (0.376)	−0.637 (0.262)	−4.331 *** (0.000)	−1.896 ** (0.029)	I(1)

Notes: ** and *** represent 5 and 1 percent significant levels, respectively. The *p*-values are indicated in parentheses. The Z [t-bar] is reported.

4.4. Panel Cointegration Test

This study utilizes residual-based cointegration tests developed by Pedroni (1999, 2004), Kao (1999), and Westerlund (2005) to examine the existence of a long-term relationship among the variables. The results of these tests, presented in Table 7, demonstrate that the null hypothesis of no cointegration is rejected at the 5 percent significance level. This provides evidence of a long-term, cointegrating relationship between national intellectual capital, institutional quality, and green innovation.

Table 7. Cointegration test results.

	Statistics
<i>Pedroni</i>	
Modified Phillips–Perron t	2.3090 **
Phillips–Perron t	−9.4901 ***
Augmented Dickey–Fuller t	−9.8559 ***
<i>Kao</i>	
Modified Dickey–Fuller t	−9.4977 ***
Dickey–Fuller t	−19.2622 ***
Augmented Dickey–Fuller t	−9.6986 ***

Table 7. Cont.

	Statistics
Unadjusted modified Dickey–Fuller t	−29.6412 ***
Unadjusted Dickey–Fuller t	−25.4425 ***
<i>Westerlund</i>	
Variance Ratio	2.0701 **

Notes: ** and *** represent 5 and 1 percent significance levels, respectively.

4.5. National Intellectual Capital, Institutional Quality, and Green Innovation Relationship

The relationship between national intellectual capital, institutional quality, and green innovation is examined using the panel dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and dynamic common correlated effects (DCCE) estimators. In the context of panel data analysis, both DOLS and FMOLS are robust methodologies for estimating cointegrating relationships. DOLS, as proposed by [Stock and Watson \(1993\)](#), addresses endogeneity and serial correlation by incorporating leads and lags of the differenced regressors, thus providing efficient estimators for cointegrating vectors. In addition, FMOLS, developed by [Phillips and Hansen \(1990\)](#), is specifically designed to handle both serial correlation and endogeneity through non-parametric corrections ([Kao & Chiang, 2000](#)). The DCCE estimator, as developed by [Chudik and Pesaran \(2015\)](#), approximates unobserved common factors using cross-sectional averages of the dependent and independent variables, making it robust to cross-sectional dependencies. These methodologies ensure consistent and asymptotically normal estimates, even in the presence of cross-sectional dependencies, making them appropriate for panel data analysis with cointegration. Table 8 presents empirical results. First, increasing national intellectual capital leads to a rise in green innovation. This positive impact supports theories within the knowledge economy literature ([Aparicio et al., 2023](#)), emphasizing national intellectual capital as a key driver of sustainable development ([Lin, 2018](#); [Vo et al., 2024](#)). National intellectual capital enables economies to leverage knowledge and skills for eco-friendly advancements.

Table 8. National intellectual capital, institutional quality, and green innovation relationship analyses using DOLS, FMOLS, and DCCE estimation techniques.

Variables	Equation (1)			Equation (2)		
	DOLS	FMOLS	DCCE	DOLS	FMOLS	DCCE
NIC	0.320 *	1.955 *	0.194 **	3.735 *	2.205 **	0.177 *
INS	0.045	0.151 ***	0.003 *	0.075	0.123 ***	0.006 *
NIC×INS				2.306	1.913 *	0.501 *
LGDP	2.379 **	2.969 ***	0.030	1.959 *	2.919 ***	−0.037
NRR	2.781	4.834 ***	−1.488	5.124	4.852 ***	−2.185
REC	0.013	0.756	0.135 *	0.254	0.644	0.056
_cons	−0.059	−0.108 ***		−0.082	−0.110 ***	
Observations	339	339	323	339	339	323
R-squared	0.069	0.256	0.570	0.141	0.241	0.400

Notes: *, ** and *** represent 10, 5, and 1 percent significance level, respectively.

In the Asia–Pacific region, economies characterized by high levels of knowledge, talent, and technological capabilities are instrumental in fostering green innovations that address environmental sustainability challenges ([Vo & Tran, 2024](#)). These findings are consistent with those of [Tebaldi and Elmslie \(2013\)](#) and [Wang et al. \(2023\)](#), who suggest that economies with higher intellectual capital are better equipped to develop innovative solutions to environmental issues. Such economies invest more in research and develop-

ment, benefit from better educational systems, and attract skilled professionals, creating an environment conducive to green innovation (Luo et al., 2023). Second, institutional quality also significantly and positively affects green innovation. This aligns with the broader knowledge economy literature, which underscores the importance of institutions in fostering innovation and economic growth (Aparicio et al., 2023; Choong & Leung, 2022). With its diverse economic landscapes and rapid development, the Asia-Pacific region provides a unique context to examine the interaction between institutional quality and green innovation. Countries in the region are increasingly recognizing the need for effective institutions to promote green innovation activities as part of their sustainable development efforts (Wei et al., 2023; Chien et al., 2024). Third, the estimated coefficients of national intellectual capital and the interaction term between national intellectual capital and institutional quality carry the same sign. This implies that as institutional quality improves, the positive impact of national intellectual capital on green innovation strengthens. The total effect of national intellectual capital on green innovation, with institutional quality, is the sum of the coefficients β_1 and β_3 , as shown in Equation (3). These findings align with research by Qiu et al. (2022) and Chen et al. (2024), which suggests that enhancing institutional quality further bolsters green innovation. For Asia-Pacific countries, advancing institutional frameworks is crucial for fostering green innovation and harnessing the benefits of green technologies.

Table 9 presents the marginal effects of national intellectual capital on green innovation at three levels of institutional quality: minimum, mean, and maximum. Using the FMOLS estimation technique, the marginal effects at these levels are -2.195 , 2.205 , and 6.685 , respectively. At the lowest level of institutional quality, an increase in national intellectual capital is associated with a decrease in green innovation by 2.195 units. Conversely, at the average and highest levels of institutional quality, an increase in national intellectual capital leads to a rise in green innovation of 2.205 and 6.685 units, respectively.

Table 9. Marginal effects of national intellectual capital at minimum, mean, and maximum of institutional quality.

FMOLS	
Indicators	Institutional quality
Marginal effects at zero	2.205
Marginal effects at the minimum level	-2.195
Marginal effects at the mean level	2.205
Marginal effects at the maximum level	6.685
Minimum institutional quality	-2.300
Mean of institutional quality	5.88×10^{-9}
Maximum institutional quality	2.341

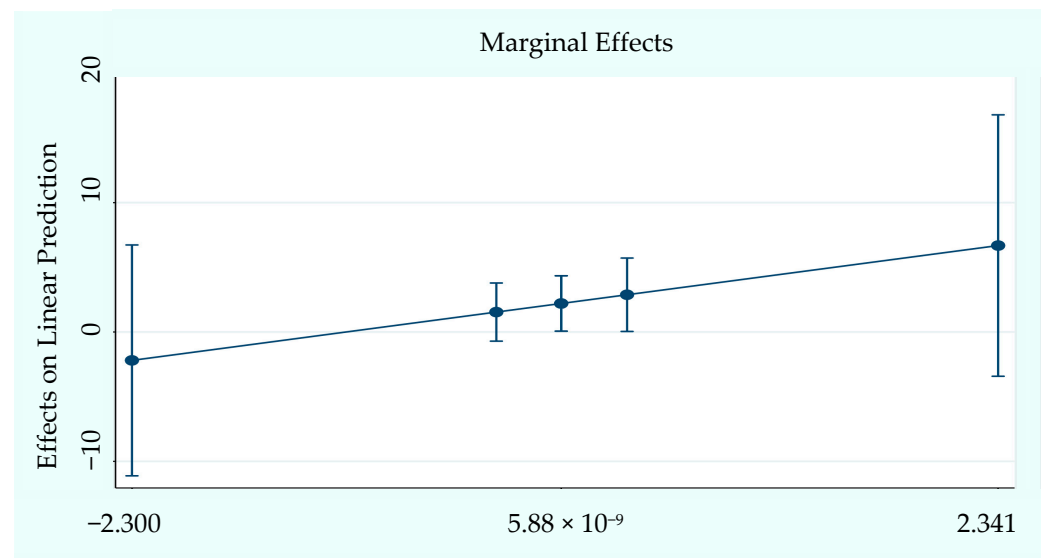
Moreover, this study unveils the marginal impacts of national intellectual capital at the 25th and 75th percentile values of institutional quality. As depicted in Table 10, the influence of national intellectual capital on green innovation at the 25th percentile level of institutional quality is quantified at 1.540. In contrast, at the 75th percentile, the impact of national intellectual capital on green innovation escalates significantly to 2.881, signifying a substantial increase compared to the 25th percentile. These findings shed new light on the relationship between national intellectual capital, institutional quality, and green innovation, providing a deeper understanding for scholars, policymakers, and industry experts.

Table 10. Marginal effects of national intellectual capital at 25th and 75th percentile values of institutional quality.

	FMOLS
Institutional quality (at the 25th percentile)	−0.347
National intellectual capital	1.540 *
Institutional quality (at the 75th percentile)	0.352
National intellectual capital	2.881 **

Notes: * and ** represent 5, and 1 percent significance level, respectively.

Figure 2 plots the marginal effect of NIC on GIN across varying levels of INS, based on the interaction terms in our model. As shown, the positive impact of NIC on GIN strengthens as INS increases, confirming the hypothesized moderating role of institutional quality.

**Figure 2.** Marginal effects of national intellectual capital at minimum, mean, and maximum of institutional quality.

4.6. Robustness Analysis

To ensure the robustness of our empirical findings, we conducted a rigorous robustness test using the pooled mean group (PMG) estimation method, as [Pesaran et al. \(1999\)](#) recommended. The results, presented in Table 11, confirm the findings in Table 8. Increases in national intellectual capital and natural resource abundance are associated with a rise in green innovation in the long term in Asia–Pacific economies. Conversely, the study also finds robust evidence that an increase in renewable energy consumption correlates with a significant decrease in green innovation over the long term.

National intellectual capital enables economies to leverage knowledge and expertise to develop eco-friendly technologies and methods for addressing long-term challenges ([Vairinhos et al., 2019](#)). Research by [Luo et al. \(2023\)](#) and [X. Zhao and Qian \(2024\)](#) shows that human capital, a key component of national intellectual capital, significantly drives green innovation. National intellectual capital improves green innovation by enhancing a nation's adaptability to new challenges, fostering creativity, and applying technological progress for sustainable goals ([Bounfour, 2005](#); [Vairinhos et al., 2019](#)). Furthermore, the impact of institutional quality on the relationship between national intellectual capital and green innovation underscores the importance of governance, regulatory frameworks, and institutional stability in promoting green innovation ([T. P.-K. Tran et al., 2022](#)). High-quality institutions create a conducive environment for national intellectual capital to thrive,

protecting intellectual property rights, reducing bureaucratic obstacles, and enhancing transparency (Rehman et al., 2024). Danta and Rath (2024) support this view, asserting that institutional quality is critical for transforming intangible assets into tangible economic and social benefits. The results align with the findings of Yang et al. (2024), who state that institutional quality in Asian countries is often pivotal in steering resources toward sustainable practices. This highlights the contextual nature of institutional impacts, suggesting that the potential of national intellectual capital can be fully realized when institutional conditions are favorable. This study contributes to the ongoing discourse by demonstrating that in Asia–Pacific economies, institutional quality strengthens the impact of national intellectual capital on green innovation in the long run, indicating that strong institutions may amplify the positive effects of intellectual capital, particularly in advancing green innovation.

Table 11. National intellectual capital, institutional quality and green innovation relationship robustness analysis using the pooled mean group (PMG) estimation method.

Variables	Coefficient	Prob *
<i>Long-run coefficients</i>		
NIC	8.403	0.000 ***
INS	−0.861	0.000 ***
NIC×INS	1.777	0.000 ***
LGDP	−0.284	0.014 **
NRR	15.305	0.000 ***
REC	−12.007	0.000 ***
Error correction coefficients	−0.361	0.001 ***
<i>Short-run coefficients</i>		
DNIC)	8.311	0.242
D(INS)	0.631	0.050 *
D(NIC×INS)	−2.409	0.043 **
D(LGDP)	3.098	0.611
D(NRR)	13.601	0.293
D(REC)	−0.355	0.951
C	−4.258	0.003 ***

Notes: *, **, and *** denote 10, 5, and 1 percent significance level, respectively.

For control variables, the positive relationship between economic growth, natural resource abundance, and green innovation is consistent with the resource-based view, which suggests that wealth generated from natural resources can be reinvested in sustainable technologies and eco-innovative practices (Shi et al., 2024). This relationship is particularly relevant for resource-rich economies in the Asia–Pacific region, where natural resources play a critical economic role (X. Li et al., 2024). Studies such as those by Manigandan et al. (2024) and Si et al. (2024) support the idea that when managed responsibly, economic growth and natural resources can fund green innovation initiatives. The findings of this paper suggest that natural resource abundance can serve as a valuable input for green innovation in Asia–Pacific economies and provide an adequate institutional framework to guide investments in sustainable directions.

One of the most noteworthy and unexpected outcomes of this study is the observed negative long-term relationship between renewable energy consumption and green innovation. This outcome supports the conclusions drawn by Wang et al. (2023), challenging the widespread assumption that greater adoption of renewable energy directly leads to increased innovation in green technologies (Sethi et al., 2024). While this result may seem counterintuitive, it aligns with observations in several Asia–Pacific countries where the renewable energy sector is undergoing a transitional phase. Firstly, this trend could imply that as these economies shift toward more established renewable technologies, the

perceived security in their energy transition may lead to a reduced emphasis on further green innovation (Rasheed et al., 2024). Secondly, the substantial financial and material investments required to maintain and expand existing renewable infrastructure might limit the availability of resources for new innovation initiatives, thereby slowing innovation momentum. These findings raise important considerations for policymakers and suggest the need for deeper exploration into how renewable energy strategies are structured and financed to ensure sustained innovation. These implications of the study's findings are thought-provoking and warrant further investigation.

5. Conclusions and Recommendations

Promoting green innovation has become a focal point for discussion and debate among scholars, industry experts, and policymakers worldwide, particularly in the Asia-Pacific region in recent times. Over the last two decades, these countries have seen a notable surge in green innovation (X. Zhao & Qian, 2024). Consequently, the impact of intangible assets, such as national intellectual capital, on green innovation has sparked intense debate, especially in the context of institutional quality. This research investigates the influence of national intellectual capital on green innovation and the moderating effect of institutional quality on this relationship, analyzing data from 17 Asia-Pacific economies between 2000 and 2020. The study also explores the incremental impact of national intellectual capital on green innovation at varying levels of institutional quality.

The study concentrates on the enduring relationship between national intellectual capital and green innovation by employing DOLS and FMOLS estimation methods for panel data. It also assesses both long-term and short-term effects using PMG estimation techniques. The findings suggest that enhancements in national intellectual capital and institutional quality bolster green innovation through various estimation approaches. Moreover, the study delves into the moderating influence of institutional quality on the nexus between national intellectual capital and green innovation. Intriguingly, the data reveals that higher institutional quality amplifies the positive effect of national intellectual capital on green innovation. Additionally, the empirical evidence points to the crucial role of economic growth and natural resource wealth in advancing green innovation within Asia-Pacific economies. This study's results also indicate that an increase in renewable energy consumption correlates with a reduction in green innovation.

This study makes several theoretical contributions to the literature on intellectual capital, green innovation, and institutional quality. The findings of this first expand the intellectual capital framework by demonstrating that national intellectual capital drives economic growth and significantly enhances green innovation outcomes. This suggests that intellectual capital should be integrated into environmental sustainability models, especially in the Asia-Pacific region, where green innovation is increasingly critical for sustainable development. Further, by identifying the moderating effect of institutional quality, this study adds to institutional theory, highlighting how strong institutional frameworks can amplify the positive impact of national intellectual capital on green innovation. This finding underscores the importance of including institutional quality as a crucial factor in theoretical models examining the sustainability impacts of intellectual capital. Finally, the study offers new insights into resource-based theory by showing that economic growth and natural resource abundance positively correlate with green innovation. These findings imply that resource-rich countries in the Asia-Pacific region could leverage their natural resources and sustained economic progress to drive innovation in environmentally sustainable practices.

From a practical perspective, this study has several implications for policymakers and business leaders. The finding of this research first emphasizes the importance of investing in national intellectual capital, as a strong intellectual base can drive green innovation

and align economic progress with environmental goals. Governments and businesses should prioritize resources for education, research, and knowledge-sharing initiatives that support green innovation. Further, since institutional quality significantly moderates the relationship between national intellectual capital and green innovation, governments in the Asia–Pacific region should focus on building transparent, supportive institutional frameworks. For businesses, this underscores the value of public–private partnerships, which could provide strategic pathways to leverage these institutional structures for innovation. The study also highlights that resource-rich countries in the region could strategically use their natural resources to promote green innovation. Firms and governments can harness natural resources as assets that drive innovation and sustainability by focusing on sustainable resource extraction and utilization practices. Finally, the unexpected negative impact of renewable energy consumption on green innovation suggests the need to re-evaluate renewable energy strategies. Rather than prioritizing consumption alone, policymakers and managers should ensure that renewable energy policies and investments actively support innovation. This might involve encouraging R&D in renewable technologies, incentivizing the adoption of innovative solutions, and considering hybrid strategies that balance renewable energy goals with the need for ongoing green innovation.

This study has several limitations. First, it focuses solely on countries in the Asia–Pacific region, which may not fully reflect the conditions of other parts of the world. Future research should consider extending this work to various global regions to enhance the generalizability of the findings. Second, institutional quality varies significantly across countries. Thus, treating institutional quality in the Asia–Pacific region as a whole may not adequately capture the unique institutional contexts of individual countries. Further studies may focus on examining institutional quality at the country level to gain a more nuanced understanding of its role in promoting green innovation. Third, this study uses the total number of environment-related patent applications as a proxy for green innovation, which may not fully capture the breadth of a country’s green innovation efforts. Future research may benefit from integrating multiple indicators to measure green innovation more comprehensively.

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