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The Role of Green Innovation Appropriability and Firm Performance: Evidence from the Chinese Manufacturing Industry

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Abstract: The growing concern over environmental degradation has pushed firms towards green innovation—technological progress that reduces environmental impact, especially in the manufacturing regime. In this context, appropriability, or the ability of firms to protect and profit from their innovations, particularly green technological innovation, becomes crucial. This paper investigates the role of appropriability in the relationship between green innovation and a firm's performance and the circumstances in which that effect will be strengthened or lessened. To conduct this study, we examined 618 Chinese manufacturing firms from 2015 to 2021 and found that stronger green innovation appropriability (GIA) leads to better firm performance. Furthermore, that positive effect is superior in discrete technology regimes than in cumulative technology regimes; nonetheless, increasing the shareholding of national institutional investors can intensify GIA's force. This study contributes to the literature on green innovation management and provides practical insight for Chinese manufacturing firms aiming to pursue sustainable production processes as well as improve their economic performance.

Keywords: green innovation appropriability; firm performance; discrete technology; national institution investors

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1. Introduction

Green innovation or eco-innovation is frequently highlighted as a critical driver of firm performance, promising benefits such as enhanced stakeholders' views [1], cost reduction, and new market opportunities [2]. However, the mechanism of green innovation to enhance firm performance remains cumulative [3] and contentious among scholars. For instance, research shows green innovation could significantly improve environmental performance [4] and a firm's innovation performance [5] but not directly improve a firm financial performance [5–7].

Several challenges hinder the effective transformation of green technology into enhanced firm performance. These challenges include the dual externalities of green innovations, difficulties in profiting from eco-products, and environmental policy rent-seeking behaviours. The knowledge generated by green innovations tends to diffuse quickly and widely, reducing the competitive advantage of the innovating firms [8]. The inherently incremental nature of most green technologies often leads to improvements that are not easily protected by patents or other intellectual property rights [9].

Moreover, policy rent-seeking activities further complicate the scenario in China. The Chinese government has implemented a range of policies and incentives aimed at promoting green innovation, such as subsidies, tax incentives, and preferential procurement policies. While these measures have successfully spurred the development of green technologies, they have also led to unintended consequences, such as firms prioritizing rent-seeking behaviours over genuine market-driven innovation [10]. Firms may engage in strategic behaviours to maximize subsidies and other policy incentives, diverting resources away from genuinely productive innovation activities. Researchers also note that policy distortions can lead to inefficient allocation of resources, undermining the potential performance benefits of green innovation [11]. Thus, helping innovators understand the rationale behind how green innovation can improve firm performance should be a significant focus for scholars.

The major concern for innovators is whether green technology can genuinely enhance firm performance or at least avoid increasing costs. While the social benefits of green innovation certainly motivate policymakers to promote eco-friendly production [12], firms need assurance that such innovations will improve their performance. This assurance serves as a continuous incentive for companies to invest in green technology R&D.

While cumulative research has studied how external policies can incentivize green innovation [13–15], few have explored how firms' inner mechanism helps to capture value from green innovation via the appropriability perspective. Scholars such as Arrow and Levin have attributed the underinvestment in innovation to a lack of appropriability mechanisms, which hampers firms' ability to recoup innovation costs [16,17]. Teece's definition of appropriability mechanisms includes both the legal protection of innovations (e.g., patents) and the commercialization of these innovations, which can reduce the extent of competitive imitation and enhance a firm's competitive advantage and value [18,19]. The theory of profit from innovation (PFI) suggests that appropriability strategies play an essential role in ensuring that firms can profit from their green innovations. However, applying the PFI framework and appropriability mechanism in the Chinese green innovation scenario is still insufficient.

Moreover, the Chinese market is characterized by a high degree of competition and rapid technological advancements, which can exacerbate the appropriability challenges faced by firms. More specifically, the fast-paced nature of 'discrete' technological diffusion means that innovations can be quickly imitated, reducing the competitive advantage of the original innovator [17,20]. Furthermore, the industrial structure in China, which includes a significant number of state capital and large conglomerates, influences the innovation landscape. Better access to government support and resources can skew the competitive balance and create barriers for smaller, private firms seeking to innovate [21].

In China, the effectiveness of green technology innovation in improving firm performance is further complicated by the regulatory and market environment. Policy rent-seeking, where firms invest in green technologies primarily to gain government subsidies rather than market-driven benefits, can distort the true value of green innovations. This phenomenon necessitates a nuanced understanding of how appropriability can mitigate such challenges and support firm performance in the Chinese context. Bridging this gap will help demonstrate the tangible benefits of green technology, thus incentivizing managers to persist in their green R&D endeavours.

This study integrates research on profiting from innovation and technological innovation management to examine the role of GIA in enhancing firm performance within the Chinese manufacturing industry. We define and identify a firm's appropriability of its green innovations, measured using a Data Envelopment Analysis (DEA) model, which illustrates the firm's ability to capture value from green technologies through patent rights protection. A previous study [22] has emphasized the importance of appropriability mechanisms in capturing the economic returns from innovation. However, there is limited research specifically addressing the appropriability of green innovations. By employing the

DEA model to measure GIA, which has been effectively used in performance measurement and efficiency analysis in various contexts [23], this research will focus on the specific appropriability strategies that can help firms capture value from their green innovations, despite the inherent challenges in the Chinese market. Exploring the relationship between GIA and firm financial performance via the OLS regression model, we argue that green innovation per sum does not significantly improve firm performance, but an appropriability strategy in green innovation can enhance financial performance. That positive impact works better in discrete industry than cumulative industry where the corporate governance could strengthen the appropriability strategy.

2. Literature Review and Hypotheses

2.1. Green Innovation and Firm's Financial Performance

The literature provides mixed evidence on the relationship between green innovation and financial performance. Numerous studies have documented a positive impact of green innovation on firm performance. By implementing green process innovations, companies enhance resource efficiency, leading to cost reductions and operational improvements. Simultaneously, green product innovations bolster corporate reputation by meeting the growing consumer demand for environmentally friendly products, thereby positively influencing financial performance [2,24]. The positive effects tend to manifest over time, with multinational firms experiencing heightened financial returns after a few years [3]. Additionally, green investments in energy firms, supported by environmental taxes, subsidies, and technological advancements, contribute to improved financial and environmental outcomes [25]. Moreover, green patenting positively influences firm performance in China, especially among state-owned enterprises [26], and the adoption of green innovations enhances competitive advantage and overall organizational performance [1,2].

The relationship between green innovation and firm performance is multifaceted, with some studies indicating neutral or negative impacts under certain conditions. Researchers suggest that while green innovation intensity positively impacts financial performance over time, it shows no significant immediate effect [3]. This implies that the benefits of green innovation may be delayed, making it less appealing for firms seeking short-term gains. Scholars also highlight that green innovative firms do not experience improved financial performance compared to non-green innovative firms, especially in contexts with stringent environmental regulations and higher normative levels [7]. This raises concerns about the immediate financial viability of green innovations under strict regulatory environments.

Some researchers explore the impact of green R&D on firm performance, finding that while such investments reduce carbon emissions, their positive financial impact is not straightforward [27]. Similarly, in Indonesian manufacturing firms, green process innovation has no significant effect on firm performance, though green product innovation does positively impact performance [28]. This distinction suggests that not all types of green innovation equally contribute to economic benefits, with process innovations possibly requiring more time or additional supportive measures to yield financial returns.

Also, green innovation can negatively impact firm value in heavy pollution industries in China, though this negative effect can be mitigated by increasing executive equity incentives and management-employee pay gaps [29]. This indicates that the success of green innovation in improving firm value might depend on specific internal management strategies and incentive structures. Furthermore, green issues can compound the positive effects of green process innovation on firm performance but not on product innovation [30], which suggests the role of management focus in determining the financial outcomes of green innovation.

These studies collectively reveal that while green innovation has the potential to enhance firm performance, its economic benefits are not universally guaranteed and can be influenced by various factors, including the type of innovation, managerial concerns, regulatory environments, and internal incentive structures. Therefore, we propose the following hypothesis to investigate the effects of green innovation further:

H1. *Green innovation does not significantly improve a firm's economic performance.*

2.2. GIA Is the Key to Profiting from Green Innovation

GIA is a new concept developed from the 'appropriability' term in the profiting from innovation (PFI) theory [18], which particularly refers to the appropriability mechanism of green technological innovation. Green technology innovation, facing the dual challenge of enhancing environmental benefits and increasing firm value, can also be examined through the PFI lens. Appropriability mechanisms play a crucial role in bridging between innovation inputs and profiting outputs. According to the PFI framework, firms can improve their financial performance through appropriability mechanisms when implementing technological innovations [18]. By applying the PFI framework to green technology innovation, we aim to analyse corporate profit strategies, providing sustainable green innovation strategies for firms in competitive markets.

Appropriability is crucial in understanding how companies can secure returns on their investments in new technologies and processes. Teece [18] introduced the PFI framework, highlighting that the effectiveness of appropriability mechanisms—such as patents, trade secrets, and complementary assets—determines a firm's capacity to profit from its innovations. Accordingly, appropriability mechanisms consist of two components: external intellectual property protection systems and internal capabilities to commercialize innovations.

This framework emphasizes that merely creating innovation is insufficient; firms must also establish strategies to protect and capitalize on their innovations to achieve competitive advantage. Over the past thirty years, PFI theory has evolved from relying primarily on exogenous intellectual property protection to incorporating endogenous mechanisms that enhance appropriability to drive firm value growth [18,19]. Some research also examined how the strength of appropriability mechanisms affects value capture, emphasizing the importance of following these mechanisms with a firm's competitive position [31]. Additionally, scholars revisited the role of intellectual property in protecting innovation rents, providing updated insights into how firms utilize these mechanisms in contemporary markets [32].

Researchers have increasingly focused on the role of appropriability mechanisms in corporate innovation management. However, there is no consensus on the exact impact of these mechanisms on innovation performance. Studies indicate a positive correlation between early-stage innovation performance and semi-formal appropriability mechanisms (e.g., contracts), while formal mechanisms (e.g., patents) show a negative correlation [33]. Stronger appropriability through patent protection or ownership of specialized complementary assets can enhance economic performance at the firm level [34]. Scholars empirically analysed data from 2392 Korean firms in 2018, showing that combining appropriability mechanisms with external collaboration improved innovation performance [35].

These findings underscore the importance of a nuanced approach to appropriability in fostering green innovation. Strengthening appropriability mechanisms is essential for firms to profit from technological innovation [36,37]. This includes leveraging external legal protections [38,39], internal business models [40], and processes that commercialize innovations. Similarly, for green technology innovation, firms can achieve profitability by enhancing the strength of their appropriability mechanisms. Firms must balance external and internal mechanisms to maximize the economic benefits of their green technological advancements, thereby contributing to both environmental sustainability and corporate profitability. Thus, this study aims to build a balanced index of internal and external metrics to measure the GIA and to further examine the following hypothesis:

H2. *GIA can help with a firm's economic performance.*

2.3. Impacting Factors of Appropriability in PFI

2.3.1. Appropriability Strategy in Discrete Technology and Cumulative Technology

The relationship between technological innovation and financial performance varies across industries due to differences in the nature of technology, which shapes how innovation contributes to firm outcomes [18,41]. From the knowledge-based view (KBV) of the firm, emphasising that knowledge is the most strategically significant resource, driving innovation and competitive advantage [42,43], green innovation can also enhance the firm performance via effective knowledge dissemination [44]. However, variations in the characteristics of knowledge affect dissemination pathways, leading to divergences in appropriability strategies across different contexts.

Knowledge varies significantly across industries in terms of its discriminability, absorptiveness, and susceptibility to spillover effects, which in turn influence the effectiveness of appropriability mechanisms. Particularly, knowledge spillovers, one crucial impactor to returns from R&D investments [45], decide the appropriability efficiency in intellectual property protection as well as in commercialisation. For example, highly tacit or firm-specific knowledge is easier to protect when secured by discrete technology, while explicit or codified knowledge may be more prone to spillovers, requiring more robust appropriability strategies [42]. In contrast, cumulative technologies, which involve iterative and interconnected knowledge flows, depend more on mechanisms like secrecy, complementary assets, and lead time to capture value from innovation [46]. The distinction between discrete and cumulative technologies significantly influences their respective appropriability strategies.

By aligning appropriability strategies with the nature of the technology and knowledge involved, firms can more effectively capture the value of their innovations and maintain a competitive advantage. Green innovation in discrete technologies, characterized by their independence [47], strong intellectual property protection [48], significant market differentiation advantages [49], and high technological regime support [50], enables firms to convert innovation more effectively into financial returns. In contrast, green innovation in cumulative technologies, due to its high reliance on collaboration, significant knowledge spillovers [51], and strong standardisation requirements [52], results in more dispersed and indirect financial outcomes.

The effectiveness of GIA on firm financial performance varies notably between discrete and cumulative technologies, largely due to differences in innovation processes and profit-making mechanisms in various knowledge discrimination paths. Appropriability strategies determine the extent to which firms can capture financial returns from their green innovations, and these strategies function differently depending on the technological knowledge regime. Thus, studying GIA in different knowledge regimes helps to figure out the PFI trail of the Chinese manufacturing industry.

Discrete technologies refer to innovations that are typically self-contained, with limited reliance on prior technologies or knowledge bases [53]. Examples include pharmaceuticals or certain engineering products. In discrete technologies, innovations are typically standalone and clearly delineated, as seen in industries like pharmaceuticals and semiconductors. These sectors rely heavily on intellectual property protections, such as patents, to safeguard innovations. Green innovation in these contexts often results in distinct products or processes that can be directly monetized. For instance, green manufacturing innovations in semiconductors, when protected by patents, enable firms to command premium pricing or secure market exclusivity, leading to superior financial outcomes [47]. The direct link between innovation and marketable output ensures that firms in discrete technologies can achieve high appropriability and financial returns.

Cumulative technologies involve a sequence of innovations where new advancements build upon existing knowledge [54]. Industries like those found in information technology or automotive industries operate differently. These sectors rely on iterative innovation processes where advancements build on prior developments. In such ecosystems, green innovation often involves shared platforms and system-wide improvements [55]. For example, green innovations in automotive manufacturing, such as energy-efficient engines or emission reduction technologies, require collaboration and standardisation across the supply chain. This collaborative nature complicates the exclusive appropriation of financial gains, as benefits are dispersed across multiple stakeholders [51]. Consequently, cumulative technologies exhibit a bigger challenge in appropriability, reducing the direct financial impact of green innovation.

The differences in technological knowledge regimes further accentuate these dynamics. Discrete technologies operate under conditions of high technological opportunity and appropriability, allowing firms to capitalize more effectively on their green innovations [48]. In contrast, cumulative technologies are characterized by challenging appropriability and higher knowledge spillovers, where financial returns are shared rather than concentrated. Additionally, discrete technologies often benefit from market differentiation strategies, where environmentally friendly products appeal to niche markets with specific environmental certifications [56,57]. This clear market positioning enhances the financial outcomes of green innovations in discrete settings [49]. Firms in discrete technology sectors generally achieve better financial outcomes from direct GIA than those in cumulative technology sectors. For instance, industries with robust intellectual property systems and well-defined innovation outputs consistently outperform sectors where collaboration and knowledge sharing dilute financial returns [50].

Given the more favourable appropriability conditions in the discrete technology industry and their direct impact on financial performance, it is reasonable to hypothesize:

H3a. *GIA in discrete technology has better effects on a firm's financial performance.*

2.3.2. Appropriability Strategy and National Institutional Investors

To consider the mechanism of appropriability in different industries, dynamic capability theory [58,59] provides a valuable framework for implicated scenarios. Dynamic capabilities enable firms to design and implement appropriability mechanisms strategically, ensuring the successful translation of innovative efforts into financial returns [60].

Firms with strong dynamic capabilities can adapt their appropriability strategies to specific industry or market conditions, such as shifting from reliance on patents in weak IP environments to employing trade secrecy or strategic partnerships [37]. Enhancing dynamic capabilities also enables firms to reconfigure resources in response to external challenges, such as regulatory changes or competitive pressures in specific industries, ensuring the appropriability strategy remains robust [61]. The ongoing profit impact of market strategies and performance is closely tied to institutional dynamics [62], especially within the Chinese market [63]. These investors often enhance the manufacturers' dynamic capabilities by providing critical resources, fostering collaboration, and encouraging strategic flexibility during green innovation.

The involvement of national institutional investors often aligns firms' strategies with national innovation policies and industrial priorities. This alignment not only encourages firms to innovate in strategically significant areas, such as advanced manufacturing and green technologies but also ensures that firms operate within a regulatory and institutional framework that supports the appropriation of innovation returns. For instance, direct environmental regulations are shown to promote green technology innovations, particularly in technology-capital-intensive industries, and institutional investors following their strategies with these regulations can amplify the positive impacts of GIA [64].

National institutional investors, such as government-backed funds or state-owned investment entities, provide financial stability and resources that enable firms to invest in long-term R&D projects [65] (e.g., green technological innovation). These resources allow firms to sense emerging green opportunities, seize them through innovation, and transform their operational processes to achieve a competitive. For Chinese manufacturers, such financial backing often reduces risks associated with innovation and facilitates the implementation of appropriability mechanisms, such as robust intellectual property protections and market expansion strategies, which is important for green technology or product launching [66].

National institutional investors also play a role in facilitating partnerships and collaborations between firms, research institutions, and government bodies. Such alliances are instrumental in developing complementary assets for fostering cumulative technologies—such as cross-section manufacturing capabilities or specialized knowledge—that are essential for capturing the value of innovations [18]. This network-building effect strengthens their capacity to adapt to changing market conditions and enhances their appropriability strategies, particularly in the cumulative technology industry.

They also facilitate continuous improvement and learning, allowing firms to refine their mechanisms for capturing value from subsequent innovations [67]. This adaptability is particularly various in different industries, where dissimilar technological characteristics and market shifts often challenge appropriability strategies. In this case, the interplay between appropriability mechanisms and national institutional investors significantly impacts green innovation, particularly within cumulative technological regimes.

National institutional investors significantly strengthen the effects of GIA, particularly within cumulative technology regimes, where pressure-resistant institutional investors positively influence green innovation in China, modulated further by political ties [15]. Similarly, robust appropriability regimes significantly improve green co-innovation performance in Taiwan's manufacturing sector, highlighting the role of effective legal protections and commercialization strategies [68].

Studies highlight that firms in China with strong ties to national institutional investors often demonstrate superior innovation performance and financial outcomes [69]. These firms leverage the dynamic capabilities fostered by investor involvement to implement effective appropriability mechanisms, such as international patenting or strategic market entry, ensuring that they secure and protect returns from their innovations. Scholars show that fund holdings also enhance corporate green innovation, mediated by corporate social responsibility disclosures, suggesting that transparency promotion by institutional investors strengthens green innovation appropriability [70]. Thus, national institutional investors play a key role in green technology innovation, with supportive financial structures enabling national institutional investors to enhance GIA by backing favourable financial conditions and regulations and maximizing economic and environmental outcomes [71]. Based on these analyses, this study proposes the following hypothesis:

H3b. *National institutional investors can strengthen GIA's effects in the cumulative technology regime.*

Building on the discussion above, we present the following research framework showing in Figure 1.

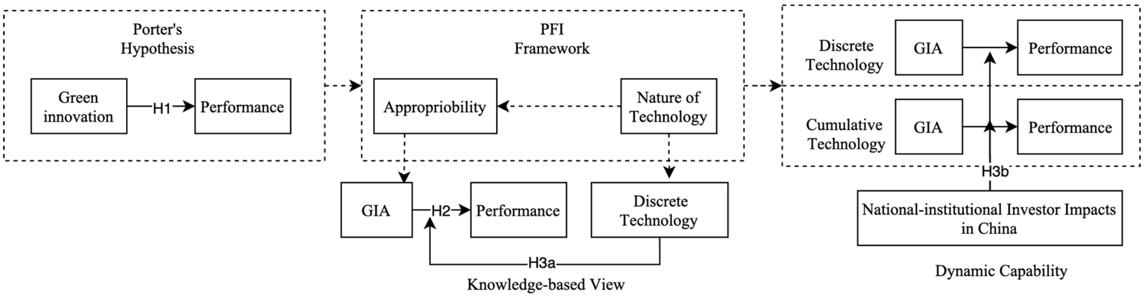

Figure 1. Research framework.

3. Research Design

3.1. Data Collection and Sampling

This study uses panel data from 618 A-share listed companies in China over a span of 7 years. Due to the unavailability of R&D investment data prior to 2015, the sample period ranges from 2015 to 2021, focusing on companies engaged in technological research and development. We processed the raw data by excluding companies that received delisting warnings, financial and insurance companies, and firms with missing R&D investment data. Ultimately, we obtained data from 618 companies, resulting in 4326 observations.

The primary data used in this research come from three databases. First, the China Research Data Service Platform (CNRD) provides data on R&D investment, the number of R&D personnel, and patent grants. Second, the financial and market data of companies come from the Resset database, which includes information on Tobin's Q, market-to-book ratio, shareholding of the national team, sales revenue, and other control variables.

3.2. Variables Measurement

3.2.1. Dependent Variable

Firm performance: this study utilizes Tobin's Q for this purpose. Market-based indicators, such as Tobin's Q and market returns, are also effective for assessing financial performance. While there is extensive debate on the appropriate measurement of financial performance, Tobin's Q is considered a key indicator in innovation research. It reflects a company's market value and potential for sustainable growth from investors' perspectives [72]. However, there is still controversy regarding the relationship between accounting-based measures, such as ROA, and market-based indicators [73].

Tobin's Q provides a comprehensive view of a firm's market valuation, integrating both current performance and future growth potential. Unlike ROA, which primarily focuses on historical accounting data, Tobin's Q captures investor sentiment and expectations about a firm's future profitability. This forward-looking perspective is particularly important in innovation research, where the potential for future growth and development often outweighs past performance [74,75].

The choice of Tobin's Q over other metrics, such as ROA, is motivated by its ability to address key challenges in evaluating innovative firms. Innovation often involves long-term investments with uncertain payoffs, making short-term accounting-based metrics less effective. Moreover, Tobin's Q is less influenced by accounting practices and standards, which can vary significantly across firms and regions. Despite its advantages, Tobin's Q has its limitations; for instance, it may be influenced by stock market volatility and external economic factors, which could distort the assessment of firm performance. Nonetheless, its applicability in capturing both present market value and future growth potential is consistent well with the objectives of this study.

3.2.2. Independent Variable

Firm's green innovation appropriability, *GIA*: We measure a firm's green innovation appropriability by multiplying the number of green patent applications (*Green*) in a given year by the firm's efficiency of technology transfer (*ETT*):

$$GIA_{i,t} = Green_{i,t} \times ETT_{i,t}$$

According to the definition of green innovation appropriability, we consider the efficiency of a firm's technology conversion of existing green patents to assess the potential social returns to the innovator. Due to the intangible nature of technological innovation, quantitative analysis is challenging, and patent data is often used to measure technological innovation and the output of innovation activities.

Patent data objectively reflect a company's technological level and innovation vitality over a period. The methods to measure green innovation include R&D, patents, and total factor productivity (TFP). However, due to data limitations, R&D and TFP are difficult to specify for the green sector or determine whether technological innovation is leaning towards green. Therefore, patent data are used as key tools to identify green technology innovation activities.

Each patent application is classified into detailed technical subcategories according to the International Patent Classification (IPC), allowing for the identification of green technology innovation activities [76]. Thus, green patent data become an important indicator of firm-level green innovation.

On the other hand, measuring a firm's efficiency of technology transfer has always been considered a challenge in innovation management research. Efficiency encompasses both inputs and outputs. Furthermore, appropriability mechanisms are not static outcomes of a single year but are continuous and dynamic features of innovation activities [18]. Therefore, we believe that using the Malmquist index, which calculates efficiency growth rates, to measure a firm's technological appropriability relative to the previous year can better reflect the strength of a firm's appropriability mechanism. This index model provides a dynamic efficiency analysis of decision-making units D over different periods. In this study, we use DEA to compute the Malmquist index under the assumption of variable returns to scale.

The Malmquist productivity index can be decomposed into changes in relative technical efficiency and technological progress [77]. In empirical research, there are two approaches to decomposing the Malmquist index. To obtain the total factor productivity with period t as the base period and $t+1$ as the comparison period, we follow the method of Fare, Grosskopf and Norris, using Fisher's concept of taking the geometric mean of two Malmquist indices to calculate productivity changes [78,79].

$$M_i\left(x^{t+1}, y^{t+1}; x^t, y^t\right) = \left\{ \left[\frac{D_i^t(x^t, y^t)}{D_i^{t+1}(x^t, y^t)} \right] \left[\frac{D_i^{t+1}(x^{t+1}, y^{t+1})}{D_i^t(x^{t+1}, y^{t+1})} \right] \right\}^{\frac{1}{2}}$$

$$= \frac{D_i^t(x^t, y^t)}{D_i^{t+1}(x^t, y^t)} \left(\frac{D_i^{t+1}(x^{t+1}, y^{t+1})}{D_i^t(x^{t+1}, y^{t+1})} \right)^{\frac{1}{2}}$$

$$= E\left(x^{t+1}, y^{t+1}; x^t, y^t\right) TP\left(x^{t+1}, y^{t+1}; x^t, y^t\right)$$

In the above formula, $E(\cdot)$ is the relative efficiency change index under the condition of various returns to scale and free disposability of inputs, measuring the extent to which each observation catches up to the best practice frontier from period t to $t+1$. $TP(\cdot)$ is the technological progress index, which measures the shift of the technology frontier from period t to $t+1$. When M is greater than 1, it indicates a growing trend in technological appropriability; when M is less than 1, it indicates a declining trend.

This study uses the number of R&D personnel and R&D investment to measure various aspects of technological innovation inputs; it uses the number of patent grants and new product sales revenue to measure the exogenous and endogenous outcomes of technology transfer. Since R&D investment typically cannot produce innovation outcomes immediately, we use patent grants instead of patent applications to reflect the time lag. Additionally, since firm-level new product sales revenue data are unavailable, we follow the method of Sofka and Grimpe (2010), multiplying industry-level new product sales revenue by the firm's return on investment to calculate the firm's new product sales revenue [80]. For samples with zero patent grants, we adopt the approach of previous scholars and replace it with a small value of 0.01 [81].

3.2.3. Moderation Variables

National institutional investors (*NI*). This study uses the shareholding of the "national team" as the indicator of national institutional investors. National institutional investors, often referred to as the "national team", are large, government-linked financial institutions that play a significant role in capital markets. These investors include sovereign wealth funds, public pension funds, and other state-owned investment entities. National institutional investors contribute to improved corporate governance and firm performance by actively monitoring and engaging with the companies they invest in [82]. Their shareholding networks enhance market information efficiency by facilitating the dissemination of information and reducing asymmetry [83]. Furthermore, they positively influence enterprise innovation by driving increased innovation investments, particularly in firms with substantial financial slack [84]. These insights collectively underscore the important role of national institutional investors in shaping firm behaviour, market dynamics, and overall economic development in China.

Discrete industry (*Discrete*). Technological areas are divided into cumulative and discrete categories, with cumulative technologies involving many patentable elements and discrete technologies having relatively few [85]. Firms in discrete industries, like chemicals, use patents to block competitors, whereas firms in cumulative industries, such as telecommunications, use patents for negotiation leverage [22]. The classification is influenced by patent policies and the nature of the product. Following the classification of Cohen [22], A dummy variable, **Discrete**, equals "1" for discrete product industries (food, textiles, chemicals, drugs, metals, and metal products) and "0" for cumulative product industries (machinery, computers, electrical equipment, electronic components, instruments, and transportation equipment).

Additionally, we selected firm size (Size), firm age (Age), firm growth (Growth), cash flow ratio (Cashflow), and management expense ratio (Mfee) as control variables. Detailed descriptions of these variables are provided in Table 1.

Appropriating the economic returns from technical innovations is very important not only for individual inventors and innovators but also for technical change in individual markets and for the whole economy. Since appropriability is difficult to measure directly, many researchers have been trying to investigate it indirectly and qualitatively by examining the effectiveness of various means. The most important of these means are patents, secrecy, lead time, and related advantages.

Table 1. Variable Descriptions.

Variable	**Name**	**Measurement**
Dependent variable	GIA	$GTA_{i,t} = Green_{i,t} \times ETT_{i,t}$
Independent variable	Firm performance	Tobin's Q value is calculated as (market value of equity + net debt)/current value of tangible assets. The specifics are as follows: For companies with only A-shares, the calculation is: A-share price × total number of shares. For companies with only B-shares, the calculation is: B-share price × total number of shares × exchange rate. For companies with both A-shares and B-shares, the calculation is: A-share price × (non-tradable A-shares + tradable A-shares) + B-share price × B-shares × exchange rate. Net debt is calculated as total liabilities minus wages payable, welfare payable, dividends payable, taxes payable, other payables, accrued expenses, and deferred tax credits. Tangible assets are calculated as total assets minus deferred expenses, intangible assets and other assets, and deferred tax debits.
Moderation variables	National Institutional Investors (NI).	The proportion of shares held by institutional investors such as the China Securities Finance Corporation, the National Social Security Fund, and Central Huijin Investment Ltd. relative to the total number of company shares.
	Discrete industry.	Dummy "1" for food, textiles, chemicals, drugs, metals, and metal products industries and "0" for machinery, computers, electrical equipment, electronic components, instruments, and transportation equipment
Control variables	Size	Number of employees in the company
	Age	Age of the company = ln (current year − year of establishment + 1)
	Growth	Growth rate of operating revenue = (current year's operating revenue/last year's operating revenue) − 1
	Cashflow	Net cash flow from operating activities divided by total assets
	Mfee	The ratio of management expenses to current operating revenue

3.2.4. Empirical Specifications

In this study, we employ a two-way fixed-effect estimator in the panel OLS regression to control for unobservable firm-specific and time-specific factors that might influence firm performance. The baseline specifications are as follows. Formula (1) is used to test H1, and Formula (2) is used to test H2, and Formulas (3) and (4) is used to test H3.

$$FirmPerformance_{i,t} = \beta_0 + \beta_1 Green_{i,t} + Controls_{i,t} + \theta_t + \gamma_i + \epsilon_{i,t} \quad (1)$$

$$FirmPerformance_{i,t} = \beta_0 + \beta_1 GTA_{i,t} + Controls_{i,t} + \theta_t + \gamma_i + \epsilon_{i,t} \quad (2)$$

$$FirmPerformance_{i,t} = \beta_0 + \beta_1 GTA_{i,t} + \beta_2 Discrete_{i,t} + \beta_3 GTA_{i,t} \times Discrete_{i,t} + Controls_{i,t} + \theta_t + \gamma_i + \epsilon_{i,t} \quad (3)$$

$$FirmPerformance_{i,t} = \beta_0 + \beta_1 GTA_{i,t} + \beta_2 NI_{i,t} + \beta_3 GTA_{i,t} \times NI_{i,t} + Controls_{i,t} + \theta_t + \gamma_i \tag{4}$$

where β's are regression coefficients. $GTA_{i,t}$ refers to firm i's GIA at time t. $Controls_{i,t}$ denotes a set of firm-specific control variables. θ_t denotes yeat fixed effects and γ_i denotes firm fixed effects. They represent unobserved characteristics that are assumed to be correlated with the dependent variables. $\epsilon_{i,t}$ is the idiosyncratic error.

4. Result

4.1. Main Result

Table 2 provides the descriptive statistics for all variables. The correlations indicate no severe multicollinearity concerns for the regression analysis. The baseline regression results are presented in Table 3. In column (1), the coefficient for Green is positive but not statistically significant, suggesting no significant direct effect of green practices on firm performance. H1 is supported. Column (2) includes GIA, which shows a highly significant positive effect on firm performance (β = 0.3641, p < 0.01). This indicates that greater GIA can improve firm performance. H2 is supported. Column (3) further includes the interaction term between GIA and Discrete industries. The coefficient for GIA remains highly significant (β = 0.4737, p < 0.01), and Discrete industries themselves have a significant positive effect on firm performance (β = 0.0646, p < 0.05). Importantly, the interaction term (GIA × Discrete) is also highly significant (β = 0.8184, p < 0.01), indicating that the effect of GIA on firm performance is considerably stronger in discrete industries compared to cumulative industries. H3a is supported. These results suggest that while green practices alone do not significantly impact firm performance, green innovation appropriability significantly enhances performance, especially in discrete industries where the effect is amplified.

Table 2. Data description and correlation matrix.

Variable	N	Mean	s.d.	Firm Performance	GIA	NI	Discrete	Age	Size	Growth	Cashflow	Mfee
Firm performance	4326	5.123	8.231	1.000								
GIA	4326	6.357	26.182	−0.018	1.000							
NI	4326	1.045	0.261	−0.021	0.142 ***	1.000						
Discrete	4326	1.167	1.623	−0.011	0.103 ***	0.072 ***	1.000					
Age	4326	2.940	0.285	−0.025	0.001	0.037	0.005	1.000				
Size	4326	8.078	1.190	−0.120 ***	0.339 ***	0.185 ***	0.298 ***	0.071 ***	1.000			
Growth	4326	0.148	0.351	0.089 ***	−0.020	−0.041 *	0.012	−0.088 ***	−0.049 *	1.000		
Cashflow	4326	0.135	0.098	−0.027	−0.016	−0.030	0.052 **	−0.024	−0.086 ***	0.006	1.000	
Mfee	4326	0.097	0.172	0.071 ***	−0.035	−0.006	−0.006	−0.091 ***	−0.164 ***	0.155 ***	0.021	1.000

Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

Table 3. Two-way fixed effects OLS estimation on firm performance.

	(1)	(2)	(3)
Green	0.0030		
	(0.0027)		
GIA		0.3641 ***	0.4737 ***
		(0.0488)	(0.0334)
Discrete			0.0646 **
			(0.0148)
GIA × Discrete			0.8184 ***
			(0.0719)
Age	−0.7647	0.1144 **	0.1303 **
	(0.5764)	(0.0396)	(0.0316)
Size	0.1405 ***	0.0590 *	0.0560 *
	(0.0301)	(0.0213)	(0.0213)

Table 3. *Cont.*

	(1)	(2)	(3)
Growth	0.0009	−0.0070	−0.0147
	(0.0599)	(0.0318)	(0.0299)
Cashflow	−0.5263 **	−0.1899 **	−0.1589 **
	(0.1342)	(0.0415)	(0.0372)
Mfee	−0.2871	0.0172	0.1378
	(1.027)	(0.1110)	(0.1304)
Fixed Effects	Firms, Years	Firms, Years	Firms, Years
Num.Obs.	4326	4326	4326
R2	0.3561	0.2056	0.2110

Signif. Codes: ***: 0.01, **: 0.05, *: 0.1. Industry cluster standard errors are in parentheses.

These findings are consistent with similar studies in other emerging markets. For example, a study conducted in Indonesia found that firms adopting green innovation strategies saw significant improvements in financial performance, particularly when supported by government incentives and institutional investments [86]. However, results in China may vary due to distinct institutional characteristics, such as strong state ownership and regulatory enforcement, which might amplify or dilute the observed effects depending on the specific sector [87].

Table 4 presents the regression results for different groups categorized by Discrete, reflecting the analysis in column (3) of Table 3. Columns (1) and (3) represent firms in the discrete technology industry, while columns (2) and (4) pertain to firms in the cumulative technology industry. To ensure the comparability of the group regression results, the seemingly unrelated regression (SUR) model was used to test for between-group differences in the variables GIA and GIA × NI.

Table 4. Results of heterogeneity analysis.

	(1) Discrete	(2) Cumulative	(3) Discrete	(4) Cumulative
GIA	0.4635 ***	0.5166	−0.9677	1.7181 ***
	(0.0146)	(0.3757)	(2.449)	(0.0613)
NI			0.0389	0.0180
			(0.4161)	(0.1126)
GIA × NI			0.1351	7.9102 ***
			(0.1296)	(0.2888)
Age	0.4263 **	−0.2108 ***	0.4325 **	−0.1774 ***
	(0.1464)	(0.0240)	(0.1440)	(0.0277)
Size	0.0803 **	0.0147	0.0797 ***	0.0149
	(0.0267)	(0.0077)	(0.0148)	(0.0078)
Growth	0.0709	−0.0422	0.0725	−0.0426 *
	(0.0398)	(0.0183)	(0.0404)	(0.0170)
Cashflow	−0.1165	−0.2239 *	−0.0812	−0.2384
	(0.1354)	(0.0871)	(0.2195)	(0.1322)
Mfee	−0.5665 **	0.0856	−0.5794 ***	0.1533
	(0.1489)	(0.0751)	(0.1188)	(0.0679)
Fixed Effects	Firms, Years	Firms, Years	Firms, Years	Firms, Years
Num.Obs.	1689	2637	1689	2637
R2	0.2092	0.3291	0.2094	0.3383
Between-Group Differences	0.002 *		0.0017	

Signif. codes: ***: 0.01, **: 0.05, *: 0.1. Industry cluster standard errors are in parentheses.

In Table 4, columns (1) and (2) compare the effects of GIA on firm performance between discrete and cumulative technology industries. In discrete technology industries, GIA has a positive and significant impact on firm performance (β = 0.4635, p < 0.001), indicating that firms in these industries benefit substantially from their green technology investments. In contrast, the coefficient for GIA in cumulative technology industries is also positive but not statistically significant (β = 0.5166), suggesting that the impact of GIA on firm performance in these industries is less pronounced and not statistically significant.

This result is consistent with evidence from other emerging economies, such as Brazil, where cumulative industries showed mixed performance outcomes due to weaker institutional frameworks and investor participation [28]. Conversely, discrete industries in Brazil exhibited strong performance gains under green innovation policies.

Columns (3) and (4) further examine the moderating effect of national institutional investors (NI) on the relationship between GIA and firm performance. In the discrete technology industry, the interaction term GIA × NI is positive but not significant (β = 0.1351), indicating that while NI presence slightly enhances the impact of GIA, the effect is not strong enough to be statistically significant. The main effect of GIA in this context is negative ($\beta = -0.9677$) and not significant, suggesting a cumulative interplay that might dilute the expected positive impact.

In contrast, for cumulative technology industries, the interaction term GIA × NI is highly significant (β = 7.9102, $p < 0.001$), indicating a strong moderation effect where the presence of national institutional investors greatly amplifies the positive impact of GIA on firm performance. Here, the main effect of GIA is highly significant and positive (β = 1.7181, $p < 0.001$), reinforcing the importance of institutional support in maximizing the benefits of green technology investments in cumulative industries. To illustrate the moderating effect of national institutional investors (NI) on green innovation appropriability (GIA), we utilized the sjPlot 2.8.17 package in R4.0 to generate a visual representation of the interaction in Figure 2

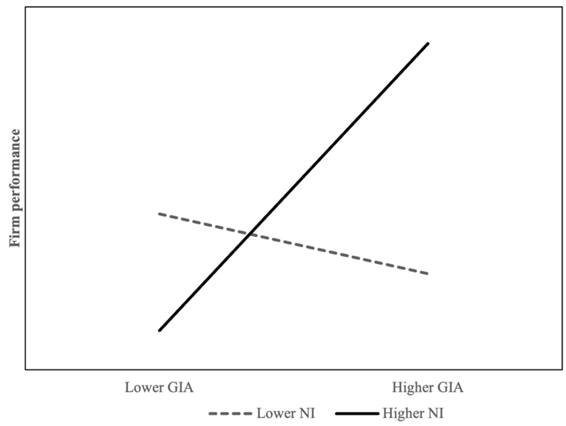

Figure 2. Moderation effect of national institutional investors on green innovation appropriability.

This pattern mirrors findings in India, where cumulative industries benefit significantly from institutional investor support due to the long-term nature of their green investments [5]. The institutional environment in China further reinforces this trend, emphasizing the critical role of government-backed financial mechanisms.

These comparisons reveal that while GIA generally enhances firm performance, the presence and influence of national institutional investors play a critical role, particularly in cumulative technology industries. This suggests that institutional investors can significantly improve the effectiveness of green technology investments. This underscores the necessity for tailored strategies that consider industry-specific dynamics and the important role of NI support in driving sustainable innovation and performance improvements [82–84].

4.2. Robustness Check and Endogeneity Analysis

In this study, the market-to-book ratio was used instead of Tobin's Q for the regressions in Tables 3 and 4, yielding similar results (Tables 5 and 6). This indicates that the conclusions of this study are robust. We employ the 2SLS model to address the endogeneity issues of column (2) of Table 3 and Column (1,2) of Table 4. We construct the instrument variable for GIA by using the Lewbel IV estimator [88]; this estimator uses heteroskedasticity to *internally* generate IVs as functions of the model's data in the first stage of regression. Table 7 shows the results. According to the result, potential endogeneity issues in *GIA* do not appear to affect our OLS estimates. Therefore, our baseline OLS estimates are favoured over the IV results because they demonstrate consistency (unbiasedness) and are more efficient, having the smallest variance.

Table 5. Robustness check for basic regression analysis.

	(1)	**(2)**	**(3)**
Green	0.0014		
	(0.0032)		
GIA		1.284 ***	0.9370 ***
		(0.0481)	(0.1524)
Discrete			0.4722 **
			(0.1418)
GIA × Discrete			0.4660 *
			(0.2206)
Age	−4.110 **	1.614 **	1.207 **
	(1.209)	(0.3639)	(0.2879)
Size	−0.0647	0.2657 ***	0.2839 **
	(0.0488)	(0.0577)	(0.0635)
Growth	−0.2057 ***	−0.1999 ***	−0.1642 **
	(0.0243)	(0.0389)	(0.0495)
Cashflow	−0.9016 **	−0.7533 **	−0.9838 **
	(0.3066)	(0.2405)	(0.2272)
Mfee	2.358 *	−2.105	−2.731
	(0.8651)	(1.406)	(1.632)
Fixed Effects	Firms, Years	Firms, Years	Firms, Years
Num.Obs.	4326	4326	4326
R2	0.8511	0.3278	0.3727

Signif. codes: ***: 0.01, **: 0.05, *: 0.1. Industry cluster standard errors are in parentheses.

Table 6. Robust check for heterogeneity analysis.

	(1) Discrete	**(2) Cumulative**	**(3) Discrete**	**(4) Cumulative**
GIA	1.141 ***	0.1389	−0.0606	4.096 **
	(0.1519)	(0.4348)	(0.5362)	(1.279)
NI			0.2535	0.0590
			(0.2447)	(0.1701)
GIA × NI			−2.1221	2.2901 ***
			(1.5744)	(0.4162)
Age	1.198 ***	3.110 ***	1.112 ***	3.105 ***
	(0.0976)	(0.2179)	(0.1758)	(0.1692)
Size	0.1238 ***	0.5930 ***	0.1182 ***	0.5896 ***
	(0.0192)	(0.0551)	(0.0132)	(0.0567)
Growth	−0.1664	−0.0700	−0.1963 *	−0.0846
	(0.1029)	(0.0388)	(0.0842)	(0.0547)
Cashflow	−1.236	−1.374 *	−1.329	−1.215
	(0.6338)	(0.4967)	(0.6271)	(0.6460)
Mfee	−2.052 **	−1.416	−1.928 **	−1.153
	(0.5693)	(1.661)	(0.4418)	(1.558)
Fixed Effects	Firms, Years	Firms, Years	Firms, Years	Firms, Years
Num.Obs.	1689	2637	1689	2637
R2	0.2092	0.3291	0.2094	0.3383
Between-Group Differences	0.0013 *		0.0001 *	

Signif. Codes: ***: 0.01, **: 0.05, *: 0.1. Industry cluster standard errors are in parentheses.

Table 7. Lewbel instrumental variable (IV) 2SLS regressions.

	(1)	(2)	(3)	(4)	(5)	(6)
IV stages	First	Second	First	Second	First	Second
Dependent Var.:	GIA	Firm performance	GIA	Firm performance	GIA	Firm performance
GIAiv	0.0549 ***		0.4366 ***		0.0542 ***	
	(3.14×10^{-5})		(0.0420)		(2.38×10^{-5})	
GIA		0.7477 ***		0.4981 ***		0.9452
		(0.0821)		(0.0130)		(0.4919)
Age	−0.0162	1.603 **	−0.0204 ***	0.4725 **	0.0507 **	−0.2115 ***
	(0.0100)	(0.3620)	(0.0041)	(0.1589)	(0.0101)	(0.0234)
Size	−0.0017 **	0.2631 ***	−0.0003	0.0804 **	−0.0005	0.0150
	(0.0005)	(0.0566)	(0.0011)	(0.0252)	(0.0010)	(0.0077)
Growth	−0.0095 **	−0.2057 ***	−0.0081 *	0.0803	−0.0063 **	−0.0421
	(0.0029)	(0.0372)	(0.0031)	(0.0450)	(0.0015)	(0.0184)
Cashflow	−0.0107	−0.7759 **	−0.0137	−0.1250	−0.0173	−0.2214 *
	(0.0073)	(0.2355)	(0.0140)	(0.1425)	(0.0175)	(0.0886)
Mfee	0.0870 *	−2.111	0.0364	−0.6597 ***	0.0577 **	0.0906
	(0.0340)	(1.423)	(0.0384)	(0.1098)	(0.0138)	(0.0756)
Fixed-Effects:						
Firms	Yes	Yes	Yes	Yes	Yes	Yes
Years	Yes	Yes	Yes	Yes	Yes	Yes
S.E.: Clustered	by: Industry	by: Industry	by: Industry	by: Industry	by: Industry	by: Industry
Observations	4326	4326	1689	1689	2637	2637
R2	0.81559	0.32682	0.83665	0.20882	0.87565	0.32900
Within R2	0.81348	0.15018	0.83178	0.03251	0.87388	0.05998
F-test (IV only)	2035.4		657.93		1931.9	

Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

5. Results and Discussion

5.1. Results Analysis

The findings presented in this study offer significant insights into the relationship between green innovation practices and firm performance, with particular emphasis on the role of green patents and GIA. The baseline regression results, as detailed in Table 3, are critical for discussing the two primary arguments: the limited impact of green patents on firm performance and the positive influence of GIA.

Green patents do not significantly improve firm performance in a direct way, which is supported by the regression results in column (1). Despite the positive coefficient for green patents, the effect is not statistically significant. This finding is consistent with the existing literature, which indicates that while green patents can bring financial benefits, these effects may vary based on the firm's size and the timing of the patent's implementation [89]. Additionally, the researcher found that the increase in green patent applications might lead to a short-term devaluation of firm value in heavily polluting industries, further supporting the notion that green patents alone may not guarantee improved economic performance [29]. This could be due to the high costs associated with obtaining and maintaining patents, as well as the uncertain and delayed returns on these investments.

On the other hand, GIA positively impacts firm performance. The results in columns (2) and (3) strongly support this argument. GIA shows a highly significant positive effect on firm performance, both in isolation and when interacting with discrete industries. This indicates that firms capable of effectively appropriating the benefits of their green innovations tend to perform better economically. This finding is consistent with research by other scholars, which highlights the importance of green innovation and the implementation of green technologies in enhancing competitive advantage and economic performance [1]. Moreover, the significant interaction term between GIA and discrete industries suggests that the impact of GIA is more important in these industries, which typically involve fewer patentable elements and clearer pathways for leveraging green innovations.

The findings from Table 4 provide an analysis of the relationship between GIA and firm performance, as well as the moderating role of national institutional investors (NI). The results demonstrate the differential impacts of GIA in discrete versus cumulative technology industries and highlight the significant role that NI plays in enhancing these effects.

In discrete industries, GIA has a significant positive impact on firm performance, suggesting that firms in these sectors are able to effectively capture the economic benefits of their green innovations. This finding is consistent with the study that environmental management systems and innovations can positively impact firm performance by enhancing operational efficiencies and reducing costs [90]. Furthermore, other researchers discuss how green manufacturing practices in discrete industries can lead to improved efficiency and reduced environmental impact, which likely contributes to the observed positive effect of GIA on firm performance in these industries [91].

Conversely, in cumulative technology industries, the impact of GIA on firm performance, while positive, is not statistically significant. This could be due to the inherent complexities and higher uncertainties in these industries, which make it more challenging to capture the full economic benefits of green innovations. Researchers suggest that in cumulative industries, the effectiveness of appropriability mechanisms may be moderated by the need for complementary assets and capabilities, which might not be fully accounted for in the current analysis [31].

The interaction term between GIA and NI is highly significant in cumulative industries, indicating that the presence of NI greatly enhances the positive impact of GIA on firm performance. This finding is consistent with the research shows that institutional investors can play a crucial role in promoting green innovation by providing the necessary resources and support, thereby overcoming the barriers associated with cumulative technology [15].

The significant moderation effect of NI in cumulative industries underscores the importance of institutional support in gaining the benefits of GIA. National institutional investors, with their substantial resources and long-term investment horizons, can provide the stability and support needed for firms to navigate the complexities of green innovation.

While green patents alone may not significantly enhance economic performance due to various challenges and limitations, GIA plays a crucial role in driving firm success, particularly when supported by institutional investors and in specific industry contexts. These findings emphasize the need for firms to develop robust strategies for appropriating the benefits of their green innovations and leveraging institutional support to maximize their economic impact.

5.2. Implication Discussion

The findings of this study have important theoretical and practical implications for understanding the relationship between green innovation, appropriability, and firm performance, particularly within the Chinese manufacturing industry.

5.2.1. Theoretical Implications

The findings of this study make significant contributions to the theoretical and methodological advancements in innovation management and sustainability research. First, this study develops the novel concept of "Green Innovation Appropriability" (GIA), extending profiting from innovation (PFI) theory into the realm of sustainable economic contexts [18]. By addressing the unique challenges of capturing value from environmentally focused innovations, this study enriches our understanding of appropriability in the green technology domain. Rather than focusing on how green technological innovation directly generates financial profits, GIA is the key to the black box.

Second, it offers a theoretical framework to examine how firms can incentivize green technological innovation from an internal perspective, emphasizing the crucial role of GIA mechanisms. This framework builds on prior research on appropriability strategies [22] and provides a lens through which firms can align their innovation strategies with environmental goals.

Lastly, this study constructs a robust measuring index for GIA using a Data Envelopment Analysis (DEA) model [23], enabling quantitative assessment of firms' ability to capture the economic benefits of green innovations. This methodological contribution lays the foundation for future empirical studies and practical applications, offering insights into optimizing green innovation outcomes across industries. This tool enables firms to benchmark their GIA practices, identify gaps, and implement strategies to improve value capture from green innovations. Policymakers can also use this metric to assess and incentivize green innovation at the industry level, promoting policies that encourage firms to adopt effective appropriability strategies aligned with environmental objectives.

Overall, this research contributes to the literature on green innovation and PFI by demonstrating that GIA is a critical mechanism in enhancing firm performance. While previous studies have highlighted the general importance of appropriability mechanisms [18,31], this study specifically focuses on the green innovation context, filling a gap in the existing literature. By employing a DEA model to measure GIA, this research provides a novel methodological approach to quantifying appropriability, which could be used not only in green technologies but also in the general innovation appropriability mechanism. This study also extends the discourse on industry-specific dynamics by showing that the effectiveness of GIA is more pronounced in discrete industries compared to cumulative industries, where the presence of national institutional investors (NI) plays a moderating role. These insights enrich the understanding of how appropriability mechanisms function under varying technological and institutional conditions.

5.2.2. Practical Implications

The practical implications of this study provide actionable insights for firms, policymakers, and investors aiming to enhance the economic and environmental impact of green innovations.

GIA as booster of financial performance

The introduction of GIA equips firms with a strategic lens to assess and improve their capacity to capture the economic benefits of green technologies. Firms can leverage this understanding to design robust appropriability mechanisms, such as stronger intellectual property protections and complementary asset management, which are particularly fundamental in industries where green innovation plays a critical role in competitiveness. To maximize financial returns from long-term green-tech R&D projects, firms should prioritize strengthening GIA. GIA serves as a dual-purpose framework: legally protecting innovations and facilitating their commercial transition into practical applications or marketable products. Effective GIA strategies can usually be identified in discrete technologies regimes, which involve intellectual property management, technology transfer mechanisms, and commercialization efforts that align with the specific characteristics of green technologies.

From a firm's perspective, investing in comprehensive patent portfolios is a critical strategy for safeguarding green innovations on a global scale. Patents provide legal protection, ensuring that firms maintain exclusive rights to their technologies, which prevents imitation and supports competitive advantage in the marketplace. By securing patents, firms can also create revenue opportunities through licensing agreements and partnerships while building barriers to entry for competitors [92]. For example, Tesla Inc. has actively patented its advanced battery management systems and other green technologies, ensuring exclusivity over these innovations. These patents have not only protected

Tesla's intellectual property but also reinforced its leadership position in the sustainable energy sector by enabling the company to focus on further R&D and market expansion [93]. Moreover, studies indicate that firms with robust patent strategies are better positioned to attract investment, as patents signal technological capability and innovation potential to stakeholders [94]. As industries worldwide adopt sustainability practices, building patent portfolios around green technologies becomes an essential element of competitive strategy, aligning long-term financial performance with environmental objectives.

Meanwhile, firms could invest in complementary assets, such as production facilities, distribution networks, and specialized human resources, to effectively scale green innovations for commercial use. These assets are crucial in bridging the gap between R&D and market deployment, ensuring that green technologies transition seamlessly into consumer-ready products. Complementary assets allow firms to produce innovations at scale, reduce unit costs, and meet market demands efficiently, thereby enhancing the financial viability of green innovations [95]. For instance, Procter and Gamble (P&G, Cincinnati, OH, USA) exemplify this approach through its development of biodegradable plastics for packaging. P&G not only secured patents to protect the intellectual property underlying these innovations but also invested heavily in production facilities to scale manufacturing, ensuring consistent supply for global markets [43]. Additionally, a strong distribution network further enables firms to penetrate diverse markets, enhancing their ability to generate revenues while advancing sustainability goals [64]. This integration of complementary assets not only supports the commercialisation of green innovations but also aligns with the firm's broader environmental and financial objectives, establishing a competitive advantage in increasingly sustainability-driven markets via GIA.

GIA efficiency mechanism

Tailoring appropriability strategies to the specific characteristics of cumulative and discrete industries is essential for optimizing the financial and environmental outcomes of green innovation. GIA works better in the discrete technologies industry. In comparison, national institutional investors play a positively moderate role in cumulative industries.

In discrete technology industries, where innovations are self-contained and more easily protected through intellectual property systems, the involvement of national institutional investors is often less impactful. In these contexts, firms can achieve financial performance by directly enhancing their GIA mechanisms by supplementing with external governance support. The firm's GIA, which focuses on legally safeguarding innovations and converting them into market-ready products, is a direct driver of financial returns. Firms in discrete technology sectors, such as pharmaceuticals or semiconductors, often rely on robust IP protections, such as patents, and complementary assets, like specialized production facilities, to capitalize on their innovations. Priority patents and trade secrets not only secure exclusivity but also enable firms to command premium pricing and maintain competitive advantages, directly boosting financial outcomes. From a governance perspective, policymakers can significantly optimize the success of appropriability strategies in discrete industries. For example, reinforcing intellectual property systems is critical to ensuring that firms can effectively protect and monetize their innovations. Stronger IP frameworks reduce the risk of imitation and enhance the financial viability of green innovations.

Conversely, in cumulative industries, such as automotive manufacturing and information technology, firms often face high levels of uncertainty and significant knowledge spillovers during green innovation processes. To navigate these complexities, firms may prioritize the involvement of national institutional investors, who play a critical role in providing financial resources, reducing risks, and fostering long-term stability in innovation ecosystems.

Institutional investors, such as government-backed funds, can leverage the findings of this research to strategically support firms engaged in green innovation, ensuring the alignment of financial and environmental returns. For example, such investors might incentive collaborative green-R&D projects by reducing market uncertainties and offering consistent funding, which is crucial for industries with incremental and dispersed innovation benefits [96]. By facilitating partnerships between firms, research institutions, and government bodies, they promote knowledge-sharing and the development of complementary assets, such as production infrastructure and standardization protocols, ensuring that green innovations transition effectively from R&D to marketable solutions [97]. Their involvement strengthens firms' ability to capture value from green innovation, maximizing both financial and environmental returns. Simultaneously, policymakers could encourage technology transfer and commercialization through Industry-University-Institute (IUI) collaborations, which have proven effective in bridging the gap between academic research and industrial application [98]. IUI collaborations facilitate the exchange of knowledge and resources, enabling firms to refine their green technologies and bring them to market more efficiently [99]. For instance, partnerships between universities and industry have been shown to significantly enhance the commercialization potential of green innovations, ultimately contributing to both economic and environmental sustainability [100].

6. Conclusions

This study provides key insights into the relationship between GIA and firm performance, particularly in the context of Chinese manufacturing firms. While regulatory and market-based policies play a significant role in promoting eco-innovation [101], this research highlights the critical importance of understanding and leveraging the internal benefits of green innovation, such as cost savings, improved operational efficiency, and enhanced competitive positioning, to sustain long-term investment in environmentally friendly technologies [102].

By introducing the concept of GIA, this study emphasizes the role of appropriability mechanisms in enabling firms to profit from their green technological innovations. Appropriability serves as an internal incentive, encouraging firms to prioritize green innovation by demonstrating how they can achieve financial returns on their investments. The findings reveal that a stronger GIA leads to better financial performance, particularly in discrete technology regimes where the pathways to appropriability are clearer and less reliant on cumulative technological interdependencies. Furthermore, this study shows that national institutional investors can amplify the positive effects of GIA in cumulative technology regimes by providing critical resources and stability.

These conclusions not only contribute to the theoretical understanding of green innovation and appropriability but also offer practical implications for firms and policymakers. For firms, developing robust appropriability strategies can enhance their ability to capture value from green innovations, thus driving both economic performance and sustainability goals. For policymakers, fostering institutional frameworks that support appropriability mechanisms and encourage investment from institutional investors can further enhance the effectiveness of green innovation initiatives.

Ultimately, this study underscores the importance of tailoring appropriability strategies to the specific contexts of different industries, as these strategies must address the distinct challenges and opportunities inherent in diverse technological and market environments. By viewing GIA as a central profiting mechanism, firms are better equipped to integrate sustainability into their core strategies, achieving a balance between economic growth and environmental responsibility. This study thus provides a foundation for further exploration of appropriability strategies in green innovation management, offering pathways for firms to thrive in an increasingly eco-conscious global market.

There are several limitations to this study that could be addressed in future research. First, this study may have overlooked certain unobserved factors within the GIA mechanism, such as organisational culture, leadership styles, or specific technological capabilities that influence how firms capture value from green innovations [103]. Exploring these dimensions could provide a more nuanced understanding of the mechanisms driving GIA effectiveness [104]. Second, while the findings focus on the manufacturing industry, future research could expand the scope to include other sectors, such as the service industry, where green innovation and appropriability strategies may operate differently due to variations in service delivery models and intangible asset utilization. For instance, the service industry often relies more on customer engagement and relational capital, which could alter the dynamics of innovation appropriability [105]. Last but not least, this study focuses on firms operating within China, and future research could examine the applicability of these insights in different national and institutional contexts. The effectiveness of GIA mechanisms may vary significantly based on regional differences in intellectual property systems, regulatory environments, and cultural attitudes toward sustainability [106]. By exploring cross-country comparisons, future studies could uncover how varying institutional and cultural frameworks influence the design and success of GIA strategies.

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References

1. El-Kassar, A.N.; Singh, S.K. Green innovation and organizational performance: The influence of big data and the moderating role of management commitment and HR practices. *Technol. Forecast. Soc. Change* **2019**, *144*, 483–498. [CrossRef]
2. Xie, X.; Huo, J.; Zou, H. Green process innovation, green product innovation, and corporate financial performance: A content analysis method. *J. Bus. Res.* **2019**, *101*, 697–706. [CrossRef]
3. Rezende, L.d.A.; Bansi, A.C.; Alves, M.F.R.; Galina, S.V.R. Galina Take your time: Examining when green innovation affects financial performance in multinationals. *J. Clean. Prod.* **2019**, *233*, 993–1003. [CrossRef]
4. Seman, N.A.; Govindan, K.; Mardani, A.; Zakuan, N.; Saman, M.; Hooker, R.E.; Ozkul, S. The mediating effect of green innovation on the relationship between green supply chain management and environmental performance. *J. Clean. Prod.* **2019**, *229*, 115–127. [CrossRef]
5. Becker, B. Green innovation strategies, innovation success, and firm performance—Evidence from a panel of spanish firms. *Sustainability* **2023**, *15*, 1656. [CrossRef]
6. Ghisetti, C.; Rennings, K. Environmental innovations and profitability: How does it pay to be green? An empirical analysis on the German innovation survey. *J. Clean. Prod.* **2014**, *75*, 106–117. [CrossRef]
7. Aguilera-Caracuel, J.; Ortiz-de-Mandojana, N. Green Innovation and Financial Performance. *Organ. Environ.* **2013**, *26*, 365–385. [CrossRef]
8. Hall, B.H.; Jaffe, A.; Trajtenberg, M. Market Value and Patent Citations. *RAND J. Econ.* **2005**, *36*, 16–38.
9. Horbach, J.; Rammer, C.; Rennings, K. Determinants of eco-innovations by type of environmental impact—The role of regulatory push/pull, technology push and market pull. *Ecol. Econ.* **2012**, *78*, 112–122. [CrossRef]
10. Goulder, L.H. Effects of carbon taxes in an economy with prior tax distortions: An intertemporal general equilibrium analysis. *J. Environ. Econ. Manag.* **1995**, *29*, 271–297. [CrossRef]

11. Li, H.; Atuahene-Gima, K. The adoption of agency business activity, product innovation, and performance in Chinese technology ventures. *Strateg. Manag. J.* **2002**, *23*, 469–490. [CrossRef]
12. Ilic, S.; Petrović, T.; Djukic, G. Eco-innovation and sustainable development. *Probl. Ekorozwoju* **2022**, *17*, 197–203. [CrossRef]
13. Porter, M.E.; Linde, C.v.d. Toward a new conception of the environment-competitiveness relationship. *J. Econ. Perspect.* **1995**, *9*, 97–118. [CrossRef]
14. Xu, J.; Ng, C.; Sam, T.; Vasudevan, A.; Tee, P.K.; Ng, A.; Hoo, W.C. Fiscal and tax policies, access to external financing and green innovation efficiency: An evaluation of chinese listed firms. *Sustainability* **2023**, *15*, 11567. [CrossRef]
15. Yang, L.; Song, S.; Liu, C. Green signals: The impact of environmental protection support policies on firms' green innovation. *Bus. Strategy Environ.* **2023**, *33*, 3258–3278. [CrossRef]
16. Arrow, K. Economic welfare and the allocation of resources for invention. In *The Rate and Direction of Inventive Activity: Economic and Social Factors*; Princeton University Press: Princeton, NJ, USA, 1962; pp. 609–626.
17. Levin, R.C.; Klevorick, A.K.; Nelson, R.R.; Winter, S.G.; Gilbert, R.; Griliches, Z. Appropriating the returns from industrial research and development. *Brook. Pap. Econ. Act.* **1987**, *1987*, 783–831. [CrossRef]
18. Teece, D.J. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Res. Policy* **1986**, *15*, 285–305. [CrossRef]
19. Teece, D.J. Reflections on "profiting from innovation". *Res. Policy* **2006**, *35*, 1131–1146. [CrossRef]
20. Laursen, K.; Salter, A.J. The paradox of openness: Appropriability, external search and collaboration. *Res. Policy* **2014**, *43*, 867–878. [CrossRef]
21. Roh, T.; Lee, K.; Yang, J.Y. How do intellectual property rights and government support drive a firm's green innovation? The mediating role of open innovation. *J. Clean. Prod.* **2021**, *317*, 128422. [CrossRef]
22. Cohen, W.M.; Nelson, R.R.; Walsh, J.P. *Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)*; Working Paper 7552; National Bureau of Economic Research: Cambridge, MA, USA, 2000. [CrossRef]
23. Cooper, W.W.; Seiford, L.M.; Tone, K.; Zhu, J. Some models and measures for evaluating performances with DEA: Past accomplishments and future prospects. *J. Product. Anal.* **2007**, *28*, 151–163. [CrossRef]
24. Farza, K.; Ftiti, Z.; Hlioui, Z.; Louhichi, W.; Omri, A. Does it pay to go green? The environmental innovation effect on corporate financial performance. *J. Environ. Manag.* **2021**, *300*, 113695. [CrossRef] [PubMed]
25. Chen, L.; Zhou, R.; Chang, Y.; Zhou, Y. Does green industrial policy promote the sustainable growth of polluting firms? Evidences from China. *Sci. Total Environ.* **2021**, *764*, 142927. [CrossRef]
26. Zhang, D.; Rong, Z.; Ji, Q. Green innovation and firm performance: Evidence from listed companies in China. *Resour. Conserv. Recycl.* **2019**, *144*, 48–55. [CrossRef]
27. Lee, K.-H.; Min, B. Green R&D for eco-innovation and its impact on carbon emissions and firm performance. *J. Clean. Prod.* **2015**, *108*, 534–542. [CrossRef]
28. Helmi, W.M.; Widiastuty, E. Effect of green innovation and green process innovation on firm performance. *J. Ris. Akunt. Aksioma* **2023**, *22*, 55–69. [CrossRef]
29. Xie, Z.; Wang, J.; Zhao, G. *Impact of Green Innovation on Firm Value: Evidence From Listed Companies in China's Heavy Pollution Industries*; Frontiers Media S.A.: Lausanne, Switzerland, 2022; Volume 9. [CrossRef]
30. Tang, C.; Zhang, G.; Naumann, S.E. When do structural holes in employees' networks improve their radical creativity? A moderated mediation model. *RD Manag.* **2017**, *47*, 755–766. [CrossRef]
31. Fischer, T.; Henkel, J. Complements and substitutes in profiting from innovation—A choice experimental approach. *Res. Policy* **2013**, *42*, 326–339. [CrossRef]
32. Mezzanotti, F.; Simcoe, T. Patent policy and American innovation after eBay: An empirical examination. *Res. Policy* **2019**, *48*, 1271–1281. [CrossRef]
33. Stefan, I.; Bengtsson, L. Unravelling Appropriability Mechanisms and Openness Depth Effects on Firm Performance across Stages in the Innovation Process. *Technol. Forecast. Soc. Change* **2017**, *120*, 252–260. [CrossRef]
34. Ceccagnoli, M. Appropriability, Preemption, and Firm Performance. *Strateg. Manag. J.* **2009**, *30*, 81–98. [CrossRef]
35. Jang, S. Does Openness Enable or Hinder Innovation Performance? The Moderating Effect of Appropriability Mechanisms. *Technol. Anal. Strateg. Manag.* **2021**, *35*, 45–58. [CrossRef]
36. Hall, B.H.; Sena, V. Appropriability mechanisms, innovation, and productivity: Evidence from the UK. *Econ. Innov. New Technol.* **2014**, *26*, 42–62. [CrossRef]
37. Pisano, G. Profiting from innovation and the intellectual property revolution. *Res. Policy* **2006**, *35*, 1122–1130. [CrossRef]
38. Brown, J.R.; Martinsson, G.; Petersen, B.C. What promotes R&D? Comparative evidence from around the world. *Res. Policy* **2017**, *46*, 447–462. [CrossRef]
39. Zhang, W.; Zhao, Y.; Tian, L.; Liu, D. Boundary-spanning demand-side search and radical technological innovations in China: The moderation of innovation appropriability. *Manag. Decis.* **2017**, *55*, 1749–1769. [CrossRef]

40. Miozzo, M.; Desyllas, P.; Lee, H.; Miles, I. Innovation collaboration and appropriability by knowledge-intensive business services firms. *Res. Policy* **2016**, *45*, 1337–1351. [CrossRef]
41. Thornhill, S. Knowledge, innovation and firm performance in high- and low-technology regimes. *J. Bus. Ventur.* **2006**, *21*, 687–703. [CrossRef]
42. Grant, R.M. Toward a knowledge-based theory of the firm. *Strateg. Manag. J.* **1996**, *17*, 109–122. [CrossRef]
43. Hart, S.L.; Dowell, G. Invited Editorial: A Natural-Resource-Based View of the Firm: Fifteen Years After. *J. Manag.* **2011**, *37*, 1464–1479. [CrossRef]
44. Chen, Y.-S.; Lai, S.-B.; Wen, C.-T. The influence of green innovation performance on corporate advantage in Taiwan. *J. Bus. Ethics* **2006**, *67*, 331–339. [CrossRef]
45. Audretsch, D.; Belitski, M. The knowledge spillover of innovation. *Ind. Corp. Change* **2022**, *31*, 1329–1357. [CrossRef]
46. Winter, S.G. Understanding dynamic capabilities. *Strateg. Manag. J.* **2003**, *24*, 991–995. [CrossRef]
47. Park, J.H.; Chung, H.; Kim, K.H.; Kim, J.J.; Lee, C. The Impact of Technological Capability on Financial Performance in the Semiconductor Industry. *Sustainability* **2021**, *13*, 489. [CrossRef]
48. Song, M.; Hooshangi, S.; Zhao, Y.; Halman, J. How does technological regime affect performance of technology development projects. *J. Prod. Innov. Manag.* **2014**, *31*, 60–74. [CrossRef]
49. Li, B.; Song, P. Driving Force Mechanism of the Core Green Technology Innovation of Equipment Manufacturing Enterprises towards Industry 5.0 in China. *Math. Probl. Eng.* **2022**, *2022*, 1–18. [CrossRef]
50. Mubarak, M.; Tiwari, S.; Petraite, M.; Mubarik, M.; Rasi, R.R.M. How Industry 4.0 technologies and open innovation can improve green innovation performance? *Manag. Environ. Qual. Int. J.* **2021**, *32*, 1007–1022. [CrossRef]
51. Liang, T.-P.; You, J.; Liu, C.-C. A resource-based perspective on information technology and firm performance: A meta analysis. *Ind. Manag. Data Syst.* **2010**, *110*, 1138–1158. [CrossRef]
52. Dugoua, E.; Dumas, M. Green product innovation in industrial networks: A theoretical model. *J. Environ. Econ. Manag.* **2021**, *107*, 102420. [CrossRef]
53. Roscoe, S.; Cousins, P.; Handfield, R. The microfoundations of an operational capability in digital manufacturing. *J. Oper. Manag.* **2019**, *65*, 774–793. [CrossRef]
54. Lin, L. Licensing strategies in the presence of patent thickets. *J. Prod. Innov. Manag.* **2011**, *28*, 698–725. [CrossRef]
55. Abadzhiev, A.; Sukhov, A.; Sihvonen, A.; Johnson, M. Managing the complexity of green innovation. *Eur. J. Innov. Manag.* **2022**, *25*, 850–866. [CrossRef]
56. Majeed, M.U.; Aslam, S.; Murtaza, S.; Attila, S.; Molnár, E. Green marketing approaches and their impact on green purchase intentions: Mediating role of green brand image and consumer beliefs towards the environment. *Sustainability* **2022**, *14*, 11703. [CrossRef]
57. Elkina, O. Market incentives for the introduction of environmentally friendly products in conditions of asymmetry between companies. *Theor. Econ.* **2024**, *7*, 70–79. [CrossRef]
58. Cuellar, S.; Fernández-Bajón, M.; Moya-Anegón, F. Similarities and differences between absorptive capacity and appropriability: A bibliometric perspective. *Benchmarking Int. J.* **2022**, *31*, 98–120. [CrossRef]
59. Oduro, S.; Nisco, A.D. From Industry 4.0 adoption to innovation ambidexterity to firm performance: A MASEM analysis. *Eur. J. Innov. Manag.* **2023**, *27*, 3060–3082. [CrossRef]
60. Bindra, S.; Bhardwaj, R.; Dhir, S. Integrating knowledge management and dynamic capabilities through TISM modeling and meta-analysis. *Manag. Res. Rev.* **2023**, *46*, 534–556. [CrossRef]
61. Bari, N.; Chimhundu, R.; Chan, K. Dynamic capabilities to achieve corporate sustainability: A roadmap to sustained competitive advantage. *Sustainability* **2022**, *14*, 1531. [CrossRef]
62. Schoeffler, S.; Buzzell, R.D.; Heany, D.F. Impact of strategic planning on profit performance. *Harv. Bus. Rev.* **1974**, *52*, 137–145.
63. Jiang, J.; Seng, J.; Huo, W.; Shi, J. Mitigating managerial short-sightedness in green technology innovation and corporate financial performance: The role of "National Team" shareholding. *Int. Rev. Financ. Anal.* **2024**, *96*, 103622. [CrossRef]
64. Cai, X.; Zhu, B.; Zhang, H.; Li, L.; Xie, M. Can direct environmental regulation promote green technology innovation in heavily polluting industries? Evidence from Chinese listed companies. *Sci. Total Environ.* **2020**, *746*, 140810. [CrossRef] [PubMed]
65. Choi, M.; Na, J. Institutional investment horizon and corporate technological diversification. *Manag. Decis.* **2023**, *61*, 746–769. [CrossRef]
66. Li, J.; Wang, Q. Effect of financial support on the green technology innovation of China's equipment-manufacturing enterprises. *Sustainability* **2024**, *16*, 7939. [CrossRef]
67. Eisenhardt, K.M.; Martin, J.A. Dynamic capabilities: What are they? *Strateg. Manag. J.* **2000**, *21*, 1105–1121. [CrossRef]
68. Chang, C.-H. Green Open Innovation Activities and Green Co-Innovation Performance in Taiwan's Manufacturing Sector. *Int. J. Environ. Res. Public. Health* **2020**, *17*, 6677. [CrossRef]
69. Zhang, J.; Li, K.; Long, C.X. Institutional investors, competition and corporate innovation: Evidence from Chinese listed firms. *Econ. Transit. Institutional Change* **2023**, *32*, 583–615. [CrossRef]

70. Guo, T. Research on the Influence of Fund Holding on Enterprise Green Innovation. *Adv. Econ. Manag. Res.* **2023**, *7*, 541. [CrossRef]
71. Lv, C.; Shao, C.; Lee, C.-C. Green technology innovation and financial development: Do environmental regulation and innovation output matter? *Energy Econ.* **2021**, *98*, 105237. [CrossRef]
72. Richard, P.J.; Devinney, T.M.; Yip, G.S.; Johnson, G. Measuring Organizational Performance: Towards Methodological Best Practice. *J. Manag.* **2009**, *35*, 718–804. [CrossRef]
73. Chakravarthy, B.S. Measuring Strategic Performance. *Strateg. Manag. J.* **1986**, *7*, 437–458. [CrossRef]
74. Hoskisson, R.E.; Johnson, R.A.; Moesel, D.D. Corporate divestiture intensity in restructuring firms: Effects of governance, strategy, and performance. *Acad. Manag. J.* **1994**, *37*, 1207–1251. [CrossRef]
75. Roberts, P.W.; Amit, R. The Dynamics of Innovative Activity and Competitive Advantage: The Case of Australian Retail Banking, 1981 to 1995. *Organ. Sci.* **2003**, *14*, 107–122. [CrossRef]
76. Johnstone, N.; Haščič, I.; Poirier, J.; Hemar, M.; Michel, C. Environmental policy stringency and technological innovation: Evidence from survey data and patent counts. *Appl. Econ.* **2012**, *44*, 2157–2170. [CrossRef]
77. Färe, R.; Grosskopf, S. Malmquist productivity indexes and Fisher ideal indexes. *Econ. J.* **1992**, *102*, 158–160. [CrossRef]
78. Ray, S.C.; Desli, E. Productivity growth, technical progress, and efficiency change in industrialized countries: Comment. *Am. Econ. Rev.* **1997**, *87*, 1033–1039.
79. Färe, R.; Grosskopf, S.; Norris, M. Productivity growth, technical progress, and efficiency change in industrialized countries: Reply. *Am. Econ. Rev.* **1997**, *87*, 1040–1044.
80. Sofka, W.; Grimpe, C. Specialized search and innovation performance evidence across Europe. *RD Manag.* **2010**, *40*, 310–323. [CrossRef]
81. Bowlin, W.F. Measuring Performance: An Introduction to Data Envelopment Analysis (DEA). *J. Cost Anal.* **1998**, *15*, 3–27. [CrossRef]
82. Chen, J.; Liu, Q.; Yan, Y. The Impact of Institutional Investors on Firm Performance: Evidence from China. In Proceedings of the 2022 7th International Conference on Financial Innovation and Economic Development (ICFIED 2022), Online, 14–16 January 2022. [CrossRef]
83. Liu, G.; Yi, H.; Yu, C.-P. Shareholding Network of Institutional Investors and the Information Efficiency of Capital Market: Evidence From China. *SAGE Open* **2023**, *13*, 21582440231210080. [CrossRef]
84. Zhang, K.; Wang, J.J.; Sun, Y.; Hossain, S. Financial slack, institutional shareholding and enterprise innovation investment: Evidence from China. *Account. Financ.* **2020**, *61*, 3235–3259. [CrossRef]
85. Von Graevenitz, G.; Wagner, S.; Harhoff, D. How to measure patent thickets—A novel approach. *Econ. Lett.* **2010**, *111*, 6–9. [CrossRef]
86. Lestari, E.; Bahar, H. Green Innovation, Financial Performance, and Firm Value: A Content Analysis Method. *Value J. Manaj. Dan Akunt.* **2023**, *18*, 115–124. [CrossRef]
87. Díez-Vial, I.; Belso-Martínez, J.; Gregorio, M.-D.-C. Extending Green Innovations Across Clusters: How can Firms Benefit Most? *Int. Reg. Sci. Rev.* **2022**, *46*, 149–178. [CrossRef]
88. Lewbel, A. Using heteroscedasticity to identify and estimate mismeasured and endogenous regressor models. *J. Bus. Econ. Stat.* **2012**, *30*, 67–80. [CrossRef]
89. Semenova, A.; Semenov, K.; Storchevoy, M. One, Two, Three: How Many Green Patents Start Bringing Financial Benefits for Small, Medium and Large Firms? *Economies* **2023**, *11*, 137. [CrossRef]
90. Wagner, M. On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms. *Res. Policy* **2007**, *36*, 1587–1602. [CrossRef]
91. Triebe, M.J.; Deng, S.; Pérez-Cardona, J.R.; Joung, B.G.; Wu, H.; Shakelly, N.; Pieper, J.P.; Zhou, X.; Maani, T.; Zhao, F.; et al. Perspectives on future research directions in green manufacturing for discrete products. *Green Manuf. Open* **2023**, *1*, 10. [CrossRef]
92. Teece, D.J. Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world. *Res. Policy* **2018**, *47*, 1367–1387. [CrossRef]
93. Ahmad, R.; Ahmad, M.J.; Farhan, M.; Arshad, M.A. The relationship within green marketing strategies and market performance of Pakistan SME's. *Hamdard Islam.* **2020**, *43*, 204–216.
94. Huang, K.G.-L.; Huang, C.; Shen, H.; Mao, H. Assessing the value of China's patented inventions. *Technol. Forecast. Soc. Change* **2021**, *170*, 120868. [CrossRef]
95. Ritala, P.; Albareda, L.; Bocken, N. Value creation and appropriation in economic, social, and environmental domains: Recognizing and resolving the institutionalized asymmetries. *J. Clean. Prod.* **2021**, *290*, 125796. [CrossRef]
96. Chen, Y.; Lin, S.; Lin, C.; Hung, S.; Chang, C.; Huang, C. Improving green product development performance from green vision and organizational culture perspectives. *Corp. Soc. Responsib. Environ. Manag.* **2020**, *27*, 222–231. [CrossRef]
97. Dangelico, R.M. Green product innovation: Where we are and where we are going. *Bus. Strategy Environ.* **2016**, *25*, 560–576. [CrossRef]

98. Ursić, L.; Baldacchino, G.; Bašić, Z.; Sainz, A.B.; Buljan, I.; Hampel, M.; Kružić, I.; Majić, M.; Marušić, A.; Thetiot, F.; et al. Factors influencing interdisciplinary research and industry-academia collaborations at six european universities: A qualitative study. *Sustainability* **2022**, *14*, 9306. [CrossRef]
99. Liu, B.; Luo, J.; Zheng, K.; Wu, F.; Zhao, X. How will industrial collaborative agglomeration affect the efficiency of regional green development? *Front. Ecol. Evol.* **2023**, *11*, 1179004. [CrossRef]
100. Perkmann, M.; Tartari, V.; McKelvey, M.; Autio, E.; Broström, A.; D'este, P.; Fini, R.; Geuna, A.; Grimaldi, R.; Hughes, A. Academic engagement and commercialisation: A review of the literature on university–industry relations. *Res. Policy* **2013**, *42*, 423–442. [CrossRef]
101. Jiang, J.; Zhang, Q. Boundary spanning strategy and tacit knowledge recombination: Analysis of joint-patent networks of patent-intensive firms. *Manag. Decis. Econ.* **2023**, *44*, 3585–3603. [CrossRef]
102. Ambec, S.; Lanoie, P. Does it pay to be green? A systematic overview. *Acad. Manag. Perspect.* **2008**, *22*, 45–62.
103. Waqas, M.; Meng, Q.; Khan, S.A.R.; Hussain, K. Technological management capabilities as a pathway toward green production and green competitive advantage. *J. Manuf. Technol. Manag.* **2024**, *35*, 1528–1553. [CrossRef]
104. Barney, J.A. A study of patent mortality rates: Using statistical survival analysis to rate and value patent assets. *AIPLA QJ* **2002**, *30*, 317.
105. Foss, N.J.; Saebi, T. Fifteen Years of Research on Business Model Innovation: How Far Have We Come, and Where Should We Go? *J. Manag.* **2017**, *43*, 200–227. [CrossRef]
106. Zahra, S.A.; George, G. Absorptive capacity: A review, reconceptualization, and extension. *Acad. Manag. Rev.* **2002**, *27*, 185–203. [CrossRef]