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The Effects of Board Capital on Green Innovation to Improve Green Total Factor Productivity

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Abstract: The economy's improvement through industrial success is also leading to environmental problems such as the production of greenhouse gases and other chemicals. Since global warming has caught the attention of researchers and authorities, environmental issues are receiving more attention. In this vein, the pressure of sustainable development goals explains the status of corporate sustainable development. Particularly, corporate green practices including green innovation and green total factor productivity have become hot topics. Therefore, how green innovation can be beneficial to green total factor productivity is a major point of concern in this study. For that, corporate factors such as the role of board capital are a new light for developing green innovation. Moreover, this study also takes the competition factor into account for green innovation. This study considers agency theory and the Porter hypothesis as the theoretical base, and the results give distinctive conclusions by using fixed effects, generalized moments methods, and feasible generalized least squares on Chinese manufacturing corporations from 2011 to 2020. After a series of tests, we highlight the benefits of board capital, particularly human capital and social capital, that help to produce firm green innovation. Additionally, we explain that market competition compels corporations to make green innovations. Further, we importantly show that market competitiveness plays a critical role in fostering relationships between green innovation and board capital. It is crucial to note that by enhancing green innovation, the goal of green total factor production can be reached. These findings shed light on the imperative environmental concerns and can be a good example for authorities and governments.

Keywords: board capital; green innovation; market competition; green total factor productivity; moderating effect

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1. Introduction

The importance of sustainable practices has been increasing with time, particularly because of sustainable development. The development of the industrial sector is leading to economic progress but also carbon emissions and other environmental concerns that reflect on natural resources [1]. The sustainable development goals have major concerns for corporate sustainable development programs. These practices enhance concern for authorities, especially in fast-developing countries such as China. The economic growth of China has been improving at a pace but also leading to carbon emissions and other environmental issues. The carbon emissions rate is much higher in China, even more than in the whole of Europe and the USA together; China contributes 27% of total global carbon emissions [2]. Furthermore, the Asian Development Bank reported that Chinese cities are among the major polluting cities in the world [3]. For example, seven of the top ten most polluted cities in the world located in China. In addition, the World Health Organization has pinpointed concerns for pollution in Chinese cities [4].

Importantly, Statistical Review of World Energy 2022 documented the rise in carbon emissions in China in the last seven years, accounting for 1/3 of the world's total emissions

each year [5]. Moreover, the Paris Agreement of 2015 also highlights Chinese emissions rate and calls on Chinese authorities to control it by 2060 [6]. The United Nations is more concerned about environmental problems that have been produced in China [7]. They are constantly monitoring the environmental and social practices of China. On the other hand, China has been achieving its renewable energy targets every year. Even while installed capacity has more than doubled, coal still generates more than 60% of all electricity [8], while wind and solar only account for 12% [9]; last year, gas accounted for 6% of energy, nuclear plants 5%, and hydroelectric plants 16% [10]. However, switching entirely to renewable energy sources will not be enough to make the nation climate neutral.

Firms are now large emitters of carbon dioxide; therefore, increasing corporate green practices is crucial for China to achieve its economic green transformation and to strengthen environmental governance globally [11]. However, the world saw a massive decline in global carbon emissions in 2020 because of the COVID-19 pandemic, but the situation is getting worse again as the economy starts improving [12]. To talk about reducing carbon emissions and pursuing sustainable development, the corporate sector must play an effective role [3]. To mitigate these difficulties, corporate green behavior is necessary. Corporate sustainability encourages higher long-term efficiency and sustainable development of the company [13].

Therefore, environmentalists, legislators, civil society groups, markets, shareholders, and policymakers are all becoming more and more concerned about sustainable development in China [2]. The sustainable development authorities are also compelling the Chinese government to work for controlling environmental problems. Additionally, environmental degradation has emerged as a significant barrier to China's economic opening and development. This has many negative repercussions for the country's reputation and economic prosperity [2]. Agenda 2030 is highly important for China because of its sustainable development goals [14]. This agenda has prosperous effects on the Chinese economy and can help to manage sustainability issues. To fulfill the demands of this agenda, China has formulated national-level plans for sustainable growth and built innovation zones in the form of green technology banks. The United Nations is playing an effective role in the promulgation of this agenda in China. In this vein, China has a strong commitment to fulfill this agenda and make valuable efforts toward the sustainable development goals [15]. In this setting, the Chinese authorities have, thankfully, implemented multiple strategies to control carbon emissions and are struggling to manage the pollution factor. To manage carbon emissions and enhance industrial social activities, numerous green strategies have been adopted by the Chinese government [3]. Moreover, the environmental situation of Chinese corporations has improved well in the midst of strict criticism from around the globe.

This situation has motivated Chinese authorities to implement more effective green practices, particularly in the corporate sector. Hence, the impression of green total factor productivity (GTFP) makes a specific contribution to the Chinese business market. GTFP normally sheds light on green development in various countries, regions, and enterprises and is comprehensively and methodically reflected by all-encompassing indicators [4]. Therefore, the concept of GTFP has become popular in the industrial sector in China and compelled firms to properly adhere to environmental legislation [16]. Various factors influence GTFP, but for corporations, green innovation offers major paybacks [3]. Hence, GTFP can be upgraded through green innovation and pinpointed as an imperative strategic factor. The discussion about green innovation has gained much attention in recent times but has not yielded satisfactory results [17]. However, it has not yet been fully investigated why some organizations invest in it more than others [3]. This situation poses valid research questions:

RQ1: How does green innovation help to further improve green total factor productivity?

RQ2: What are the forces responsible for this green innovation?

Particularly, these are top executives or corporate governance factors drawing the attention that may influence green innovation. For instance, top executives such as board

members serve as major corporate governance factors. Researchers are now paying closer attention to board members' qualities for social performance [18]. Thus, board capital, therefore, emphasizes the actual skills of board associates in terms of environmental performance [19]. Therefore, the function of board capital is quite popular for green innovation. Additional questions are posed here:

RQ3: Is board capital valuable for company green innovation?

RQ4: If the function of the board's capital can enhance the company's green innovation practices, then what are the factors behind it?

This study suggests using market competition to raise board capital and promote green innovation, because competition forces companies in developing economies to develop unique goods and gain a first-mover advantage to increase earnings and reputation [20]. Moreover, numerous studies in the past have backed up the importance of competition for green innovation or other social activities [21]. Due to increased global market competitiveness, board members and other senior administrators are forced to implement some innovation or differentiation techniques, and they do this by promoting corporate social responsibility as well as green innovation [20]. Thus, we suggest that market competition concepts can be employed to enhance green innovation and serve as moderators for board capital leading to green innovation. Our understanding is that no prior research has specifically examined the multiple factors behind green innovation that help to produce GTFP, particularly the moderating impact of market rivalry.

This study selects manufacturing firms falling under the A category from Shenzhen and Shanghai Stock Exchange China from 2011 to 2020. Firstly, the fixed effect model was adopted, then the GMM model was used, and lastly, the FGLS model was adopted for further results checking. We found notable results that show that board capital, which comprises elements of both human and social capital, is substantially and positively associated with green innovation. Further, green innovation is important when there is competition available. Notably, market competition can act as a positive moderator for the improvement of board capital and the green innovation connection. Finally, we conclude that green innovation is quite favorable for green total factor productivity. The outcomes can be valuable for governments and authorities to control environmental problems.

The remaining portions of the study are broken up into different sections. Hypothesis development with relation to theories and empirical discussion is covered in Section 2. The techniques for data collection, variable measurement, and study are covered in Section 3. The empirical findings from the analysis are presented in Section 4. Section 5 unveils the additional investigation. The conclusions and suggestions can be found in Section 6.

2. Development of the Hypothesis and Theoretical Discussion

Board members are supposed to be top executives in a corporation. Therefore, they try to minimize agency conflict, and improving environmental performance is the best approach to manage this issue [21]. Agency theory sheds light on removing managerial conflicts, and board members can play an imperative role in reducing them [22]. Board capital is supposed to be a monitoring function and serve as a forefront for major decision-making [8], because the board of directors supervises and directs the managerial aspects properly and encourages managers to make transparent actions to reduce agency expenses [23]. In this vein, Gupta et al. [24] also highlighted the importance of top management for social practices as well as for technology adoption. Hence, the role of board capital could never be ignored in corporate social practices. Moreover, board capital reduces agency concerns as well as focuses on strategic decision-making through greater skills, expertise, and network connections [16]. We first rely on an agency theory for supporting the function of board capital for corporate green innovation.

Moreover, managerial issues can be solved through corporate green innovation practices [25]. Board executives promote innovative actions and serve as an inside factor in managers' decision-making. Therefore, key corporate governance factors can be a good monitoring tool for management [26]. Likewise, the function of market competition

for producing green innovation reflects the Porter hypothesis. The first-mover benefits can be enjoyed by such businesses that are involved in innovative actions [20]. Additionally, businesses with green innovations can differentiate themselves in a cutthroat industry, increasing their profitability. Porter et al. [20] supported the green innovation practices for corporate green growth. Here, green growth is considered as green total factor productivity. Market competition not only puts pressure on firms but also controls their managerial activities [27]. Furthermore, market competition stimulates the board members or other executives to make innovations.

2.1. Board Capital

The term green innovation is a different stage prolonged method where new and unproven concepts are produced and sold; therefore, it requires a lot of top-level assistance [28]. This assistance should include improved board monitoring and guidance [18]. The board's role is particularly strengthened especially in the implementation of corporate environmental policies and it helps green practices [29]. They further contend that increasing board capital benefits the development of green technology. Moreover, board capital has good skills, knowledge, education, and experience leading to green innovation. Board capital plays a significant role in the corporate sector, particularly on the board, which helps to pinpoint better recommendations, and board members have a good education that entices them to participate in environmental practices [30].

The efficacy of organizations is considerably increased by directors with higher education degrees. Similarly to this, directors who possess better knowledge and skill are familiar with competitive strategies through environmental moves [29]. According to Muttakin et al. [19], companies that want to boost innovation are more likely to look for directors with specialized training and skills to join their boards. Experience, education, and skills are indeed different capabilities that might enhance company creativity. Moreover, board capital, according to Ramón-Llorens et al. [31], was found to be an excellent tool for enhancing research and development at the corporate level. Further, they reported that having specialists on the board, particularly those with backgrounds in finance and law, enhances environmental outcomes.

Employee communication also matters for corporate sustainable growth [32]. Similarly, the skills and expertise of a board's members have an impact on a company's strategic orientation. Senior executives' educational background and professional experience are positively correlated with a company's innovation activities [33]. In light of this, the board capital supports enhanced expertise and better strategic guidance that supports effective monitoring of innovation activities [34] and better oversight for companies operating in extremely unpredictable circumstances. In addition, board social capital such as interlocking directorates fosters green innovation. Moreover, the board capital speeds up the application of social policies through useful resources. After thoroughly examining all board aspects, Jain and Jamali [35] assert that building social and human capital is essential for improving CSR, particularly environmental enactment. Board capital enhances board oversight, which reduces management entrenchment and boosts green innovation performance. The current study, therefore, hypothesizes that in light of the aforementioned literature:

H1. *A firm is more likely to have green innovation if it has greater board capital.*

2.2. Market Competition

Green innovation and development are the way of the future since they have strong policy support. Market competition pointedly produces business innovations as an external factor influencing managers' decision-making, as a competitive environment increases a firm's capacity for innovation and production efficiency, which is consistent with [27]. For instance, a study found a better correlation between corporate green innovation and top executives in competitive sectors [36]. The detrimental impact of intense market rivalry is demonstrated by the aggravation of the link between labor costs and corporate

green innovation [21]. It takes innovators some time to blend environmental and traditional corporate green innovation traits because of environmental externalities. Then, through continual technological development, they convert environmental factors into competitive advantages [35].

The status of market competitiveness must, therefore, be taken into account by managers when making all strategic decisions, including those involving corporate social practices [26]. Additionally, it makes the case that developing environmental responsibility fosters stronger connections with stakeholders. Green innovation development can, therefore, be a cause of competitive gain in terms of resources and reputation [20]. Increased market competition for industrial products and a lack of market power may inhibit green innovation, since they have a negative impact on firm profitability and the resources that can be distributed to stakeholders.

So, depending on the competitive context, green innovation might be viewed as a worthwhile competitive approach. According to Porter, companies that implement green innovations will benefit from being first to market in a competitive market. Environmental contamination has recently increased around the world, making green innovation an issue that corporations find appealing [37]. Furthermore, Cai et al. [17], argued that green innovation is a crucial tool for lowering obstacles to global trade and innovation in competitive markets. Besides, You et al. [38], observed that businesses are willing to spend on social activities to establish a differentiation strategy when they are up against greater competition. Therefore, this study has another hypothesis, as follows:

H2. *A firm is more likely to have more green innovation if it has market competition.*

2.3. The Moderating Effect

According to You et al. [24], competition limits management's ability to pursue its interests, which lowers agency costs and boosts business performance. Board capital is a significant contributor to green innovation as well as a key indicator of board effectiveness. Furthermore, the fight against industrial pollution has elevated corporate governance and corporate social responsibility to significant issues [39]. Additionally, fostering green practices is a vital component for enhancing a business's social endeavor [21]. Furthermore, boards can create green innovation-focused board procedures to entice businesses to fund and support sustainability initiatives in the competitive conditions for attaining green innovation [29].

Thus, in this vein, board directors demonstrate the values for ensuring the standard of social events [30]. Board capital would enhance professional knowledge and experience, resulting in a favorable impact on green innovation through a competitive market. Companies in highly competitive markets are forced to heavily rely on board guidance to avoid making decisions that could have an adverse impact on green innovation. High competition compels firms to improve their corporate governance structures. PMC not only enhances firm profit but also plays a role as external governance for improving the internal corporate governance structure [37].

Additionally, market competition should be a successful external model of corporate governance for enhancing internal corporate governance structures such as board capital and company profit [38]. Higher competition leads to the improvement of corporate top executives, which automatically enhances firm innovation [20]. In addition, Babar et al., [40], showed that competition has importance for firms because corporate governance practices automatically improve in this situation. Kamarudin et al. [29] discovered that firm-level competition positively enhances the efficiency of the firm board. Moreover, Babar and Habib [40] highlighted that board structure, as part of internal corporate governance, matters for corporate performance in an extremely competitive state. Thus, this study proposes a third hypothesis, as follows:

H3. *Board capital and green innovation have a stronger relationship when there is greater market competition.*

2.4. Green Total Factor Productivity (GTFP)

GTFP is imperative for corporate social development as well as the promotion of innovations. This factor is valuable for the improvement of production function as well as enhancing corporate concerns for resources and the environment [16]. GTFP is generally related to the undesirable energy usage and pollution practices by corporations for growth, which also refer to green economic performance [41]. The factor of green innovation can be an important tool for improving green total factor productivity, because technology upgrades and transformations are also associated with total factor productivity, and innovation can ultimately enhance the performance of this factor [42].

In addition, the innovation spurred by corporate competition also stimulates total factor productivity. For utmost innovation, particularly in the energy sector, the state factor of inclusive social responsibility is also applicable [43]. Generally, innovation consists of two kinds: firstly, input innovation, which can be achieved through green innovation, and then, this input further improves the second kind of output in the form of GTFP [1]. It also eliminates out-of-date production capacity, enhances the enterprise's production and operational efficiency, and decreases unexpected output to achieve green total factor productivity growth. The market competition not only enhances green innovation but also grows GTFP [4]. Further, the hunger for innovation in the market is leading to the development of GTFP as a means of improving corporate infrastructure, operations, production, and efficiency [2].

Various scholars supported the role of input innovations for output growth [1,41]. The productivity improvement is also leading to a better corporate reputation. If the corporate total production is environmentally friendly, the factors of trust and confidence can also be achieved [44]. Once a corporation achieves green innovation, the factor of self-reputation also forms, which ultimately improves green total factor productivity. Furthermore, corporate stakeholders are also putting pressure on firms for social practices and corporate growth [4]. In this vein, green total factor productivity is supposed to be a valuable tool. Figure 1 unveils the research framework. Finally, this study develops another hypothesis, as follows:

H4. *Green innovation can be valuable for green total factor productivity.*

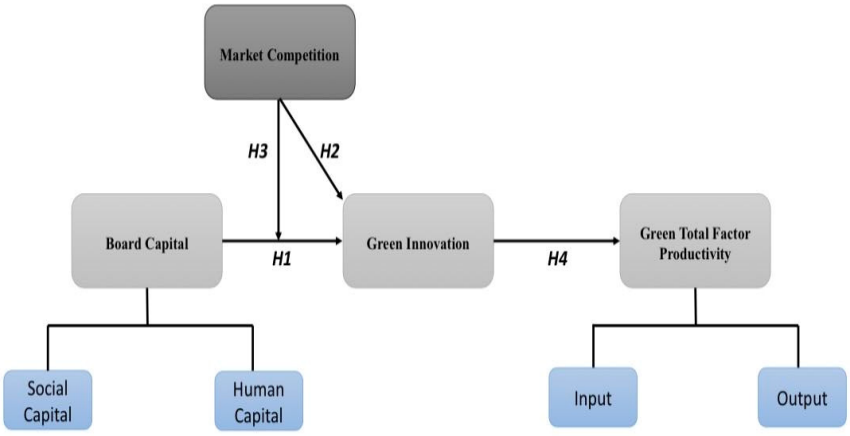

Figure 1. A visual explanation of the research concept.

3. Sample and Data

Sample selection is important for every study. Therefore, this study carefully chooses the sample. The industrialized sector is considered the main cause of conservational problems in China. The Chinese economy is growing at a fast pace due to industrial

development, but it is also creating environmental problems. The authorities identify the manufacturing sector for more pollution and other malpractice activities. The majority of carbon emissions come from the manufacturing sector because of the massive production system [4]. In addition, manufacturing enterprises in China are thought to pollute more [17]. China's manufacturing companies have access to abundant resources, high levels of production, and higher investment rates in environmental remediation. Manufacturing industries are a significant contributor to climate change, waste, air, and water pollution [17].

On the other hand, the authorities are more concerned about manufacturing companies in China, and thus, this sector is actively engaged in environmental protection activities [16]. It is a huge responsibility of manufacturing companies to expose social activities and shed light on environmental policies [3]. For achieving sustainable development goals, the industrial sector has huge importance in the form of environmental and social management. The Chinese industrial sector is expanding quickly every year and also has pollution effects. As a result, we select A-listed companies in the manufacturing industry from the Chinese stock exchanges, namely, the Shenzhen and Shanghai stock exchanges, respectively, from 2011 to 2020. We selected 26 different sector companies to complete the study objectives. These manufacturing sectors include computer equipment, petroleum refining, cooking oil, rubber, biological commodities, household electronics, plastics, chemical making products, fabrics, metal industry, paper industry, food industry, machinery, ferrous metals, non-ferrous metal, beverage, miscellaneous, textile and food processing, electrical machinery, non-metallic minerals, special equipment making, electronics making, transportation equipment, pharmaceuticals, and chemical allied products.

These following criteria were applied for the collection of data: first, firms were excluded due to unavailable data or other, missing environmental variables. Second, businesses with negative net assets were not included in the data sampling. Third, firms with special treatment such as ST, *ST, and STT were not part of our sample. Moreover, financial firms were also excluded from the sample. Further, to avoid data outliers, 1% and 99% quartiles were tracked for continuous variables. Finally, we omitted businesses whose data were not accessible. The China Securities Regulatory Commission provided direction for registered firms, and we carefully followed the directions while choosing corporations. We finally collected patent information from the corporations' yearly reports and searched the China Stock Market and Accounting Research Database for final data. The carbon emissions data came from authentic Chinese sources such as China emission accounts and datasets. Finally, 300 businesses were selected to finish this investigation, totaling 3004 observations.

3.1. Variable Measurement

Table 1 explains the variable measurements used in this study.

Table 1. Variable Explanation.

Variables	Indicators and Calculation
Dependent Variable: Green total factor productivity measured by Xia et al. [41]	GTFP is divided into input and output. Input Factors: 1. Capital (CL): firm's net fixed assets are considered for capital. 2. Labor (LB): firm's labor size is used for labor. 3. Energy (EN): the firm's operational income to local financial income is multiplied by regional energy usage. Unexpected Output Factors: 1. Sales revenue (SR): the firm's sales revenue is considered. 2. Carbon dioxide (CD) emissions: the firm's carbon dioxide emissions are considered.

Table 1. *Cont.*

Variables	Indicators and Calculation
Core Explanatory Variable: Board Capital. For better understanding the board capital impact, we divided the board capital into the human and social capital measured by Ramón-Llorens et al. [31].	Board Human Capital (BHC) 1. Board members' experience and educational achievement to the board size. Board Social Capital (BSC) 1. Using the number of simultaneous director's posts in other businesses.
Mediator: Green innovation measured by Cai et al. [17].	Green Innovation (GI) 1. Number of patent applications filed by companies.
Moderator: The technique of Herfindahl–Hirschman Index (HHI) adopted for determining market competition measured by Giroud and Mueller [26].	Market competition (MC) 1. Collection of sales based on the square of all market shares for a specific industry, we employed HHI to purposefully promote market competition. Additionally, we considered HHI when categorizing our companies as having low or high competitiveness. In a less competitive market, the firm is believed to be losing ground if the computed HHI is more than 0.01 (100). In contrast, the firm is considered to be losing ground in a more cutthroat market if the computed HHI is less than 0.01 (100). It is considered to be lowly competitive if the estimated HHI shows a strong value or more than 0.01 (100); otherwise, it is considered to be highly competitive. $\mathrm{HHI} = \sum_{i=1}^{N_{jt}} S_{ijt}^2,$ S_{ijt} stands for the firm market share, while j represents the industry, the year, and N_{jt} No. businesses in a year.
Control Variables: For proper support, we adopted multiple control factors, including board size, board independence, business size, liquidity, and environmental awareness.	1. Board size (BS): The number of board members serves as a gauge of a board's size [18]. 2. Board independence (BI): how many independent directors there are compared to all other board members [18]. 3. Corporate size (FS): The usual log of the company's entire assets is used for the calculation of size [45]. 4. Liquidity (LQ): current assets to current liabilities [45]. 5. Environmental awareness (EA): Dividing the entire workforce from the quantity consumed by the corporation on reshaping and greenery-related expenses [45].

3.2. Empirical Models

Panel data reveal unobservable heterogeneity, which is the fundamental problem. Econometrics shed light on the reputation of the fixed effect model, which is further explained as the stationary panel model [46]. We are using corporate-level panel data, and it needs proper model selection. First, there is the existence of heterogeneity, which generally refers to variable omitted bias that is available in panel data [47]. This is accomplished by accounting for factors that are connected with the predictors but that we cannot observe, are unavailable, or cannot be assessed: for example, variables that are constant over time yet differ amongst entities. However, for the second condition, variables are not shared by different entities yet are changing over time. Thus, in this vein, the analysis of this study firstly employs both the fixed effect model and the random effect model in response to this evaluation. The Hausman test finding decides the accuracy of the fixed effect.

Moreover, the prior examination has shown that some other problems such as endogeneity also exist in panel data [45]. Endogeneity is a word used in econometrics to describe instances when an explanatory variable is allied with the error term. Endogeneity is frequently caused by mislaid variables, simultaneity, and sample choice [48]. A variable that affects both a predictor variable and the dependent variable happens to be left out of the model, which is known as omitted variable bias. Therefore, to remove the endogeneity and improve the accuracy of the results, we adopted the generalized method of moment (GMM) technique. Supporting the role of GMM for panel data and reducing endogeneity is backed by numerous scholars [49,50]. The GMM model is one of the finest techniques

to cover endogeneity issues from panel data, and it helps to provide the correct findings. Various scholars have backed the GMM technique to solve this problem as well [51].

Moreover, the problem of data outlines also exists in panel data that may produce residual correlation [52]. When each random variable in a series has a fixed variance, it is known as homogeneity of variance. Additionally, if all of the random variables in a series have the same finite variance or homogeneity of variance, then the sequence of random variables is homoscedastic [53]. If the random variables in a series have the same finite variance or homogeneity of variance, then the sequence of random variables is homoscedastic. In this vein, Qiu et al. [54] unraveled the solution to data outliers and heteroscedasticity by using feasible generalized least squares (FGLS). FGLS was developed in 1934 to help correct this issue [55]. FGLS is the most effective strategy for handling heteroskedasticity. To ensure that the outcomes are accurate, we thirdly rely on the application of FGLS for further robust tests.

3.3. Econometric Model

The following econometric model has been developed to investigate the study's intentions.

$$Y_{i,t} = \alpha_1 + \beta_1 X_{1i,t} + \gamma_1 Z_{i,t} + \mu_{i,t} \quad (1)$$

The industry is represented by the subscript i. The year is indicated by the subscript t. $Y_{i,t}$ represents the green innovation, which is an explanatory variable at the moment. $X_{1i,t}$ reveals both kinds of board capital.

$$Y_{i,t} = \alpha_2 + \beta_2 X_{2i,t} + \gamma_2 Z_{i,t} + \mu_{i,t} \quad (2)$$

Equation (2) shows $Y_{i,t}$ (green innovation) as the dependent variable for this study in industry i and year t. $X_{2,i,t}$ reveals the market competition.

$$Y_{i,t} = \alpha_3 + \beta_3 X_{1i,t} + \beta_4 X_{2i,t} + \beta_5 X_{1i,t} * X_{2i,t} + \gamma_3 Z_{i,t} + \mu_{i,t} \quad (3)$$

Equation (3) shows $Y_{i,t}$ (green innovation) as the dependent variable for this study in industry i and year t. $X_{1i,t} * X_{2i,t}$ reveals the interaction between board capital and market competition.

$$Y_{i,t} = \alpha_4 + \beta_6 X_{3i,t} + \gamma_2 Z_{i,t} + \mu_{i,t} \quad (4)$$

Equation (2) shows $Y_{i,t}$ (green total factor productivity) as the dependent variable for this study in industry i and year t. $X_{3,i,t}$ reveals the green innovation here. From Equations (1)–(4), $\gamma_n Z_{i,t}$: highlights the control variables for all equations. $\mu_{i,t}$: reveals the error term; α_n: constant term, $n = 1$; β_m, γ_n are coefficients to be estimated; $m = 1, 2, 3, 4, 5, 6$.

4. Findings and Discussion

After the empirical analysis, we report descriptive stats and correlations found in Table 2. These results consist of multiple values such as mean, standard deviation, and Pearson correlations. The consequences pinpoint the variables' solid and advantageous association. The correlation between each of the control variables is also positive and significant. There are three degrees of significance for this test: 1%, 5%, and 10%.

Table 2. Descriptive Statistics and Pearson Correlation.

Variables	M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. CL	0.03	0.05	1													
2. LB	0.05	0.08	0.73 ***	1												
3. EN	1.12	1.89	0.68 ***	0.74 ***	1											
4. SR	0.43	0.72	0.74 ***	0.78 **	0.98 ***	1										
5. CD	0.09	0.02	0.97 ***	0.67 ***	0.59 ***	0.71 ***	1									
6. GI	0.14	0.18	0.74 ***	0.78 ***	0.83 ***	0.82 ***	0.67 ***	1								
7. BHC	0.73	0.94	0.67 ***	0.67 ***	0.88 ***	0.86 ***	0.60 ***	0.93 ***	1							
8. BSC	0.14	0.18	0.79 ***	0.84 ***	0.78 ***	0.84 ***	0.74 ***	0.95 ***	0.88 ***	1						
9. HMC	0.26	0.68	−0.11 ***	0.09 ***	−0.15 ***	−0.15 ***	−0.10 ***	0.03 **	−0.04 **	0.03 **	1					
10. BS	6.36	5.14	0.19 ***	0.10 ***	0.20 ***	0.21 ***	0.19 ***	0.21 ***	0.25 ***	0.20 ***	−0.24 ***	1				
11. BI	0.23	0.40	0.45 ***	0.51 ***	0.46 ***	0.44 ***	0.38 ***	055 ***	0.48 ***	0.56 ***	0.08 ***	0.02 ***	1			
12. FS	0.51	0.53	0.64 ***	0.64 ***	0.60 ***	064 ***	0.59 ***	0.73 ***	0.66 ***	0.79 ***	0.01 ***	0.12 ***	0.67 ***	1		
13. LQ	0.43	0.44	−0.02 ***	−0.03 ***	0.09	−0.05 ***	−0.06 ***	−0.08 ***	−0.12 ***	−0.08 ***	0.07 ***	0.24 ***	0.23 ***	0.17 ***	1	
14. EA	0.07	0.08	0.10 ***	0.21 ***	0.29 ***	0.20 ***	0.04 ***	0.15 ***	0.16 ***	0.10 ***	−0.02 ***	−0.04 *	0.46 ***	0.09 ***	0.42 *	1

p-value denoted by ***, **, *, which indicate 1%, 5%, and 10% significant levels, respectively.

We adopted the fixed model and GMM model for empirical analysis. The results are shown in Table 3. First, model 1 reveals the BHC impact on GI with coefficient values 0.149 and 0.153; it is highly significant, which means that the board human capital is really helpful for producing green innovation. Second, model 2 reveals the BSC impact on GI with coefficient values 1.074 and 1.112; it is also highly significant, which means that the board social capital can be a good tool for producing green innovation. The Hausman test findings for models 1 and 2 are also shown, respectively, in Table 2 (β = 73.82, p = 0.01, β = 88.78, p = 0.01), which means the adoption of the fixed effect model is suitable here. The study's initial hypothesis that board capital can aid in the promotion of green innovation was thus supported by these findings. Additionally, model 3 highlights the HMC impact on GI with coefficient values 0.034 and 0.043; it is highly significant, which means that the market competition plays a role in producing green innovation. Hence, H2 is supported here, which holds that market rivalry can also be advantageous for green innovation. The Hausman test findings for model 3 are also shown in Table 3 (β = 78.39, p = 0.01), which are highly significant and favor the use of the fixed effect method.

Table 3. Results of Links between BHC and GI, BSC and GI, HMC and GI.

Variables	Model 1		Model 2		Model 3	
	Green Innovation		Green Innovation		Green Innovation	
	FE Approach	GMM Approach	FE Approach	GMM Approach	FE Approach	GMM Approach
BHC	0.149 ***	0.153 ***				
BSC			1.074 ***	1.112 ***		
HMC					0.034 ***	0.043 ***
BS	0.001 ***	0.012 ***	−0.001 ***	−0.002 ***	0.003 ***	0.001 ***
BI	0.005 *	0.005 *	0.022 ***	0.018 ***	0.021 ***	0.007
FS	0.047 ***	0.042 ***	−0.027 ***	−0.029 ***	0.236 ***	0.252 ***
LQ	−0.041 ***	−0.049 ***	0.024 ***	0.037 ***	−0.201 ***	−0.270 ***
EA	0.029	0.048 **	−0.064 ***	−0.033 *	0.042	0.198 ***
Constant	0.006 ***	0.003	−0.001	−0.007 ***	0.064 ***	0.062 ***
R^2	0.8843		0.9184		0.6395	
F	20.47 ***		24.09 ***		14.14	
Observations	3006	2403	3006	2403	3006	2403
Hausman Result	73.82 ***		88.78 ***		78.39 ***	
Wald Chi^2		333,332.40 ***		44,711.49 ***		3654.39 ***

p-value denoted by ***, **, *, which indicate 1%, 5%, and 10% significant levels, respectively.

In addition, Table 4 lists the H3 findings. First, model 1 reveals coefficients of (BHC × HMC) 0.292 and 0.237, which are highly significant, meaning that market competition strengthens the connection between BHC and green innovation. Similarly, model 2 reveals coefficients of (BSC × HMC) 0.019 and 0.021, which are highly significant, meaning that market competition also strengthens the connection between BSC and green innovation. The Hausman test findings for models 4 and 5 are also shown, respectively, in Table 4 (β = 907.02, p = 0.01; β = 51.81, p = 0.01), indicating the adoption of a fixed effect model is suitable here. Finally, our findings supported H3.

Lastly, Table 5 reveals the findings for the connotation GI and GTFP. This study used five different dimensions of GTFP: CL, LB, EN, SR, and CD. Model 1 shows a fixed effect and GMM models result with CL, (β = 0.143, p = 0.01, β = 0.149, p = 0.01). Model 2 reveals the fixed effect and GMM models result with LB, (β = 0.299, p = 0.01, β = 0.329,

$p = 0.01$). Model 3 reveals the fixed effect and GMM models result with EN, (β = 9.596, $p = 0.01$, β = 10.84, $p = 0.01$). Model 4 reveals the fixed effect and GMM models result with SR, (β = 3.381, $p = 0.01$, β = 3.644, $p = 0.01$). Model 5 reveals the fixed effect and GMM models result with LB, (β = 0.057, $p = 0.01$, β = 0.058, $p = 0.01$). The Hausman test findings for models 1–5 are also shown, respectively, in Table 4 with a higher significance level (β = 53.96, $p = 0.01$; β = 65.05, $p = 0.01$; β = 68.19, $p = 0.01$; β = 86.68, $p = 0.01$; β = 63.66, $p = 0.01$), thus supporting the use of fixed effect method. Finally, these findings revealed the importance of green innovation for the upgrading of GTFP.

Table 4. The Moderating Results.

Variables	Model 4		Model 5	
	Green Innovation		Green Innovation	
	FE Approach	FE Approach	Fixed Effect	GMM Approach
BHC	0.143 ***	0.148 ***		
BSC			0.891 ***	0.892 ***
HMC	0.010 **	0.012 **	−0.001	−0.004
BHCHMC	0.292 ***	0.237 ***		
BSCHMC			0.019 ***	0.021 ***
BS	0.001 ***	0.003	−0.002	−0.006 ***
BI	0.005 **	0.004 **	0.017 ***	0.014 ***
FS	0.043 ***	0.038 ***	−0.021 ***	−0.023 ***
LQ	−0.036 ***	−0.044 ***	0.017 ***	0.019 **
EA	0.029 *	0.048 **	−0.071 ***	−0.079 ***
Constant	0.003	0.001 *	0.001	0.004
R Square	0.9013		0.9371	
F	18.45 ***		25.32 ***	
Observations	3006	2403	3006	2403
Hausman Result	907.02 ***		51.81 ***	
Wald Chi^2		35,180.95 ***		66,960.41 ***

p-value denoted by ***, **, *, which indicate 1%, 5%, and 10% significant levels, respectively.

Table 5. GI Effects on GTFP.

Variables	Model 1		Model 2		Model 3		Model 4		Model 5	
	CL		LB		EN		SR		CD	
	FE Approach	GMM Approach	FE Approach	GMM Approach	FE Approach	GMM Approach	FE Approach	GMM Approach	FE Approach	GMM Approach
GI	0.143 ***	0.149 ***	0.299 ***	0.329 ***	9.596 ***	10.84 ***	3.381 ***	3.644 ***	0.058 ***	0.057 ***
BS	0.004 ***	0.001 **	0.001 *	0.001 ***	−0.021 ***	−0.018 ***	−0.002	0.001	0.001 ***	0.003 ***
BI	−0.001	0.002	0.004	0.003	0.064	0.016	−0.081 ***	−0.051 **	−0.002 **	−0.001
FS	0.008 ***	0.011 **	0.006 **	0.006	−0.168 ***	0.252 ***	0.026	0.001	0.003 ***	0.005 **
LQ	−0.007 ***	−0.006	0.002	0.010	0.288 **	0.823 ***	−0.083	0.081	−0.004	−0.005
EA	0.009 ***	−0.024	0.077 ***	0.142 ***	0.957 ***	2.633 ***	0.438 ***	0.969 ***	0.001	−0.011
Constant	0.001	−0.004	−0.002	0.030 ***	−0.061 **	0.712 ***	−0.009	−0.228 ***	0.005	−0.001
R^2	0.6959		0.6808		0.7023		0.6866		0.010	
F	5.36 ***		12.04 ***		16.34		17.47 ***		5.67 ***	
N	3006	2403	3006	2403	3006	2403	3006	2403	3006	2403
Hausman Test	53.96 ***		65.05 ***		68.19 ***		86.68 ***		63.66 ***	
Wald Chi^2	989.20 ***		2949.52 ***		7866.70 ***		7435.13 ***		642.19 ***	

p-value denoted by ***, **, *, which indicate 1%, 5%, and 10% significant levels, respectively.

Discussion

Developing nations are struggling to gain attention in the international market and social actions may help them to attain this goal [45]. Moreover, multiple researchers, for example, Khanna et al. [30] and Jain and Jamali [35], supported the H1 findings. According to the fundamental research, boards that have well-educated, experienced members with external connections perform better when it comes to green innovation. Numerous plausible arguments highlighted the effective use of board capital for significant green innovation. Boards with superior human capital offer better guidance and supervision since they can assimilate complex information more rapidly thanks to higher education and experience levels. Board members are consequently intrigued by green and corporate social practices.

Our H2 was validated by prior scholars [17] because competition forces companies in developing economies to develop unique goods and obtain a first-mover gain to increase earnings through reputation [20]. Moreover, in a highly competitive market, management has few chances to use company funds for private gain. Therefore, the top executive cannot be involved in fraudulent practices. The competition factor forces the corporate executive to develop innovation. Similarly, due to increased global market competitiveness, businesses in developing nations are enhancing their corporate green innovation efforts. Our H3 results are also consistent with prior findings [29,38]. Because of the high market competition, the board members are compelled to formulate some innovation or differentiation strategies, and thus, they promote corporate social aspects such as green innovation [20]. Moreover, businesses in developing nations, especially China, are under greater pressure from the global market to abide by environmental regulations. Furthermore, there is evidence to support the adoption of green innovation activities as a result of intense industrial rivalry, which forces businesses to maintain or improve profitability.

Our last hypothesis is also associated with prior findings such as those of Xia et al. [41] and Zhang et al. [16]. Green innovation is valuable not only for profits but also for improving production factors. Green total factor productivity enhances corporate transparency in the market. Furthermore, the Chinese authorities are more concerned about environmental problems, and they have the proper corporate environmental policies that produce green innovation. Besides, firms earn appreciation from the government for making environmentally friendly practices a total factor of production. In China, where there is higher industrial competition, the pressure from society is also present, which compels the firms to participate in green innovation and green production.

5. Additional Investigation

A robustness test was applied through FGLS that helped to correct the heterogeneity issue as well. The panel data normally consist of different periods, and heteroscedasticity issues may exist. In this vein, researchers assert that by employing FGLS, issues such as autocorrelation and heteroskedasticity can be resolved [56]. Table 6 shows another test of all hypotheses, and all hypothesis results were significant and matched to the previous findings. As a result, each of these FGLS results supported the conclusions reached by all earlier techniques, such as the robustness test.

Table 6. The Robustness Results with FGLS.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
	GI		GI		GI	CL	LB	EN	SR	CD
	FGLS	FGLS	FGLS	FGLS	FGLS	FGLS	FGLS	FGLS	FGLS	FGLS
BHC	0.154 ***			0.144 ***						
BSC		1.023 ***			0.891 ***					
HMC			0.012 ***	0.013 ***	0.005 ***					
BHCHMC				0.693 ***						
BSCHMC					0.015 ***					
GI						0.134 ***	0.296 ***	8.607 ***	3.065 ***	0.061 ***
BS	−0.001 ***	0.002 ***	0.001 ***	−0.005	0.002 ***	0.001 ***	−0.002	0.009 ***	0.002 ***	0.001 ***
BI	0.008 ***	0.006 ***	0.043 ***	0.007 ***	0.009 ***	0.004	0.018 ***	−0.397 ***	−0.154 ***	−0.002 ***
FS	0.041 ***	−0.017 ***	0.239 ***	0.026 ***	−0.018 **	0.012 ***	0.011 ***	0.096 ***	0.095 ***	0.005 ***
LQ	−0.004 ***	−0.009 *	−0.101 ***	−0.004 ***	−0.001 ***	−0.001 ***	0.003 ***	0.047 ***	−0.038 ***	−0.001 ***
EA	−0.002	0.026 ***	0.312 ***	0.005	−0.004 ***	−0.003 **	0.044 ***	3.041 ***	0.705 ***	−0.006 ***
Constant	0.001	0.002 *	0.009 ***	−0.001 ***	0.001 ***	−0.004 ***	−0.003 ***	−0.331 ***	−0.066 ***	−0.001 ***
N	3006	3006	3006	3006	3006	3006	3006	3006	3006	3006
Wald Chi^2	2451.04 ***	8332.11 ***	23,916.17 ***	16,697.87 ***	315,280.15 ***	15,067.04 ***	15,265.35 ***	30,803.47 ***	27,268.11 ***	17,500.57 ***

p-value denoted by ***, **, *, which indicate 1%, 5%, and 10% significant levels, respectively.

6. Conclusions and Policy Implications

The green innovation improvement factors are being discussed through board capital. Does a company's board capital influence the development of the skills necessary for better performance in green innovation? If true, how exactly does board capital advance the success of green innovation? Therefore, we used market competition for the improvement of green innovation and as a moderating effect on the link between board capital and green innovation. The basic purpose of this study was to advance GTFP. For that, this study finally investigated the connection between green innovation and GTFP. To accomplish this, we selected Chinese manufacturing companies for the years 2011 through 2020. This study discovered that board capital and green innovation have a favorable correlation. Moreover, the study's second conclusion was that market competition fosters green innovation. This study's third conclusion was that market competition as the moderator has positive effects on the association, with board capital and green innovation. Lastly, the study concluded that GTFP is enhanced by efforts in green innovation.

We present numerous policy implications of this approach. The study emphasizes the importance of green innovation for improving green total factor productivity. Therefore, governments and authorities must consider the competency of board members for the improvement of corporate environmental issues. This study sheds light on the imperative part of board capital that is quite beneficial for industrial growth as well. Moreover, this study also highlighted the importance of board capital for corporate social practices, which has rarely been investigated before. Therefore, for better social practices, the board functions can never be ignored. It is necessary to consider the study's implications for the Chinese context, where there is a huge carbon emissions issue from the industrial sector.

Independent boards are ineffective in the Chinese market. However, on the other hand, industrial competition is very tight in the Chinese market. Therefore, this study promotes the role of market competition in the improvement of corporate social practices such as green innovation. Since board capital improves resource provision as well as the board's monitoring function, our study offers a solution to the bad corporate governance issues that are pervasive in China. Furthermore, we suggest that the companies choose directors with advanced degrees, solid functional backgrounds, expertise, and board membership if they want to pursue green innovation and environmental goals vigorously. Practitioners in China will benefit from paying close attention to the education, experience, and external connections of board members to address environmental challenges and advance sustainable development. Our research could also help businesses attract owners, stakeholders, and investors from both developed and emerging nations to join them in a highly competitive market. For businesses looking to increase their profit and cultivate effective boards, the function of strong monitoring such as market competition would be of paramount importance.

Importantly, this study suggests that the development of GTFP is imperative for the long-term success of the business. Because businesses have options to acquire green innovations to deal with environmental regulations, GTFP can compensate for their conservational cost. To improve environmental management and satisfy international standards, businesses in developing economies concentrate on green innovation for green production. In addition, the governments or authorities should impose substantial costs on polluting businesses that do not use cleaner production methods. They must develop a precise model that instructs companies to calculate their total factor productivity. According to our research, if businesses want to maintain environmental legitimacy in the face of difficult market conditions and inadequate institutional frameworks, they should improve green total factor productivity.

We found some specific flaws that could be upgraded in future probes. This study mainly considers the Chinese market, but future research may examine several emerging nations or compare those nations to developed nations. This study used competition as a moderator; in the future, more moderating factors can be selected, such as enterprise patterns and other aspects of affiliation such as board capital and green innovation.

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