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Carbon Intensity and Green Transition in the Chinese Manufacturing Industry

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Abstract: The carbon emissions in China contribute to around one-third of the world total. Therefore, China plays a critical role in global carbon emissions reduction. Over the last few years, the Chinese government has implemented a range of counter-measures to accelerate the green transition. In this research, we empirically investigate the relationship between carbon intensity and the green transition. Based on provincial panel data of Chinese manufacturing industries from 2008 to 2019, we measure the relationship between carbon intensity and green transition capacity in 30 provinces, employing the Generalized Method of Moments (GMM) to examine their influencing mechanism and regional heterogeneity. Furthermore, we use an intermediary model to investigate the influence of financial development on the relationship between carbon intensity and manufacturing green transition. We find that a U-shaped relationship exists, where increasing carbon emissions restrain the green transition initially but improve it later, such that the transition upgrades gradually. Regarding the regional heterogeneity, the GMM results show that carbon intensity has the most significant impact on the green transition in the central provinces, followed by western provinces. Meanwhile, financial performance is an essential contributor to the relationship, as more funds flow into contamination-dominated but profitable projects, thus inhibiting the transition. Urbanization and marketization are also included into threshold models, which suggest the existence of relevant threshold effects in the relationship. These findings have a referenced value suggesting that the local governments follow the U-shaped theory to reform the local carbon reduction policies and green development target according to the regional economic performance and geographical advantages.

Keywords: carbon emissions; manufacturing industry; green transition; regional heterogeneity; intermediary effect; generalized method of moments

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1. Introduction

With the rapid growth of its economy since the Reform and Opening Up in 1978, China has faced considerable pressure regarding its environmental resources, due to the sheer volume of contaminants. While the annual growth rate of carbon emissions in China has remained at 5.6% since 2000, the Chinese government aims to peak the carbon emissions by 2030, which will then be reduced to around 50%, compared to 2005, with carbon neutrality achieved by 2060 [1]. China accounts for over 50% of the global energy consumption, attributed to its manufacturing industry, which occupied approximately 28.1% of global production in 2019 [2]. To deal with the drawbacks in innovation, industrial structure, and quality, China has proposed a strategic target in "the Twelfth Five-Year Plans", aiming to upgrade the manufacturing industry and improve its core competitiveness, accordingly balancing the relationship between carbon emissions and economic growth, which is a long-term task for the manufacturing industry [3]. These facts call for China to transform toward a green economy.

With the rapid development of the Chinese manufacturing industry, carbon reduction has become increasingly important for China, in order to transform from a traditional to a high-quality development model [4,5]. Many studies have shed light on this topic. Cao and Karplus [6] have found that the Chinese carbon emissions reduced from 2006 to 2015 due to decreased coal consumption. Hou and Thompson [7] have described that the green manufacturing transition has been ongoing in most Chinese provinces since 2015, and the environmental pollution has been under control, but the global financial crisis in 2018 served to drive carbon emissions. Furthermore, some studies have revealed methods for reducing carbon intensity. Lin et al. [8] examined the movements of carbon emissions among the different industrial sectors and showed that energy consumption is the critical factor resulting in carbon emissions. As such, energy-saving technologies may significantly reduce carbon intensity. Lee et al. [9] have adopted distance functions to calculate the factor value of carbon emissions in the 30 Chinese manufacturing sectors and argued that industrial capital may improve the production efficiency of the coal and oil industries, which facilitate China meeting the low-carbon green development target. Meanwhile, Chang et al. [10] have documented that reducing the carbon intensity may facilitate carbon reductions, while investments stimulate carbon emissions. On the contrary, Chen [11] and Zhao [12] have argued that improving capital productivity and green investments may contribute to carbon reductions in China. Nevertheless, Chinese economic growth is unlikely to slow down in the short term [13].

Research has shown that China has been initiating green transition strategies for manufacturing sustainability, in terms of the capability of green transition [14,15], determinants [16,17], and policies [18]. For instance, Cheng and Li [19] have investigated the contributions of research and development (R&D) and technology to green transition and assessed the Chinese manufacturing sector's green growth quality from 2003 to 2015. Based on the evidence of manufacturing competitiveness from G20 countries, Dou [20] has shown that innovations and technologies may facilitate the transition from comparative to competitive advantages. Subsequently, this industry is dominated by high-quality and value, rather than low-quality products. The green manufacturing transition refers to its structural balance and upgrade, where manufacturers must invest in resource-saving equipment to achieve sustainable development [21].

The Chinese government has released a range of policies to facilitate the green transition, thus partially improving resource efficiency and reducing resource mismatch. Ren et al. [22] have suggested that technology innovation is a win-win strategy for environmental and economic performance, based on the evidence of Chinese pollutant discharge policies. Yi et al. [23] have argued that the Chinese environmental policies cannot drive green technology innovation. On the contrary, Yuan and Xie [24] have documented that environmental administration may facilitate the upgrading of industrial structures, based on the panel data from 30 provinces in China. They discussed how environmental policies affect the investment returns of manufacturing firms, guide consumer demands, and change resource allocation patterns, which all call for industrial transition and upgrade. Meanwhile, policy lag and administration inefficiency may eventually restrain industrial growth and result in a dilemma between the industrial upgrade and the carbon reduction target. Therefore, it is a big challenge for the Chinese government to deal with this trade-off.

These executive policies aiming to reduce carbon emissions unilaterally cannot facilitate the green transition in the long run because this kind of executive engagement does not comply with the economic rules. Firms at an early stage prefer to invest in profit-driven projects with intensive carbon emissions; they decline green development because green transformation incurs certain costs in the short term, and the mandatory carbon reduction policies limit firms' R&D investment scale [25]. By contrast, they pursue sustainable green growth generating substantial environmental and social benefits in the long run when they enter a mature stage because they have sufficient profit to support the transition [26]. Having this discussion, this study proposes and investigates a U-shaped association between them to account for it, arguing that carbon emissions restrain the green transition initially but improve it later, such that the transition upgrades gradually.

Research shows that the relationship between carbon intensity and industrial structure varies at different economic development stages [27]. Zhang and Ma [27] classified this relationship into four categories: contaminated, pollution-clean, cleaning hysteresis, and enhanced cleaning. On this basis, we propose that the relationship between carbon intensity and green development undergoes four processes: carbon emission-dominated (DB), carbon-reducing (BC), greening transforming (CA), and green-dominated (AE). The left side of Figure 1, consisting of DB and BO, means unsustainable carbon-drove growth stages, where higher firm performance growth is driven by more carbon emissions. In contrast, the right side represents sustainable green development stages at which there is more green development and higher firm performance. The manufacturing firms must undergo the two underperforming stages (BO and OA) to achieve sustainable green growth.

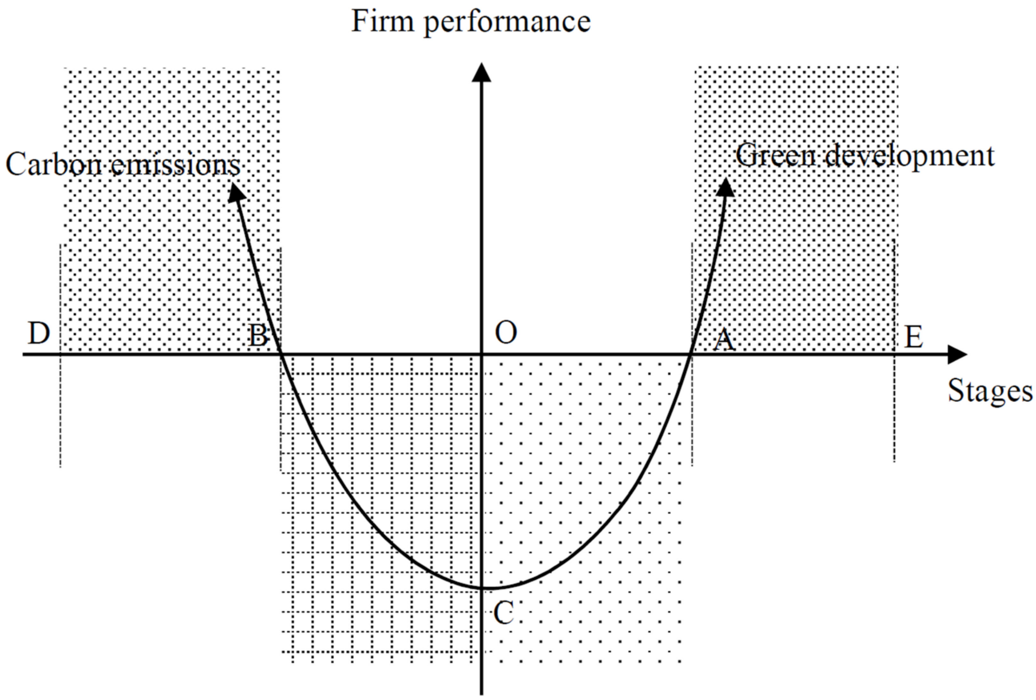
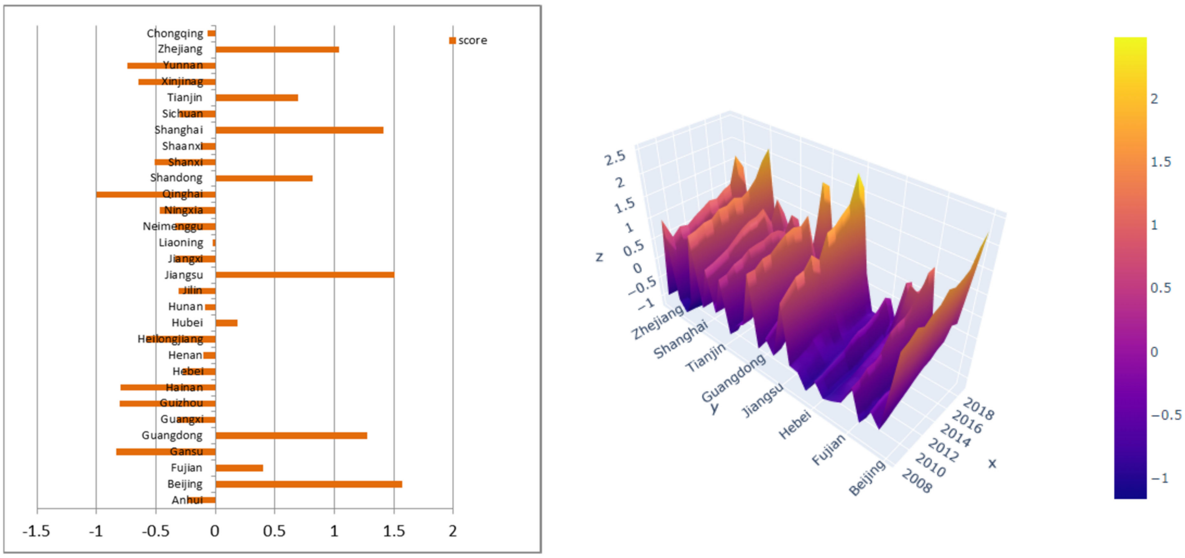


Figure 1. Four development stages of a firm from its startup to the entire green development.

The existing literature documents that the green economy may facilitate carbon reduction [7,28,29], but the research on how the manufacturing firms' carbon emissions impact the green transition in China is few and far between. This study is expected to bridge this gap, investigating how the carbon intensity in the manufacturing sector impacts the green industrial transition. Both environmental and economic policies could yield win-win benefits for carbon reduction and economic development [26]. Therefore, the most significant contribution of this research is suggesting that the policymakers release appropriate carbon reduction policies according to the firms' growing status.

China is the biggest global manufacturer; its manufacturing industry dominates its economy. Accordingly, carbon emissions in this industry significantly impact the national and even international carbon intensity. In this context, the green transition is expected to contribute to industrial sustainability. The existing research has mainly investigated the relationship at a country-specific level, while few studies have focused on provincial heterogeneity. As China has over 30 provinces, with each province having unique natural resources, industrial structures, and policies, the desire for the green transition of the firms from different provinces with various economic performances varies. Figure 2 shows the green transition status in China, particularly in the economically developed provinces and cities, including Zhejiang, Jiangsu, Guangdong provinces, Beijing, and Shanghai (see Figure 2a). These places gradually transformed toward a green economy from 2008 to 2018 (see Figure 2b), but a non-environmentally friendly model drove this transition.

Additionally, there are regional differences in the carbon reduction effect of green credit; the green credit policies improve environmental quality in resource-based regions more than in the rest of the regions [30]. Therefore, it is of great significance to explore the spatial heterogeneity of the association between carbon intensity and green transition and it is suggested that the carbon reduction policies should vary according to different regional economic performances and their geographical advantages.



(**a**) (**b**)

Figure 2. The green upgrade efficiency of each province in China from 2008 to 2018 (**a**) and its distribution in the major regions from 2008 to 2018 (**b**).

Last but not least, most studies have used static models to investigate this relationship; however, the traditional ordinary least squares and fixed effect models cannot measure the effective values. In this study, we use a dynamic method to investigate the relationship and its lag effect. Consequently, this study bridges the above-mentioned gaps, exploring the impact of carbon intensity on green transition based on the Chinese provincial manufacturing data. We evaluate the total green transition scores for each Chinese province through various indices, in terms of development performance, the environmental ecosystem, and green potential.

Under the circumstances of China's carbon peak and carbon neutrality and industrial structure upgrade, this study follows a mind-map (from policy implementation to carbon reduction to green upgrading) to investigate a green upgrading route of Chinese manufacturing firms. In particular, using the data from the 30 Chinese provinces and cities, we employed an entropy weight method to assess the green transition capacity of the manufacturing firms, as well as Fixed Effect (FE) and Generalized Least Squares (GLS) regression models to investigate the relationship between carbon intensity and green upgrading of these firms. We also adopted a dynamic panel model to further investigate the relationships and lag effects associated with green upgrading. Furthermore, financial development is included in the intermediary models, in order to explore the mechanism by which the carbon intensity influences the green transition. Finally, the threshold effects of marketization and urbanization on the green transition are discussed.

The remainder of this paper is organized as follows: Section 2 presents the research hypotheses. Section 3 outlines the methodology and data. Section 4 presents and analyzes the results. Section 5 discusses the results of the study. Finally, Section 6 concludes this research.

2. Hypotheses

Many studies have explored carbon emissions intensity from various perspectives, such as policy implementation, influencing factors, dynamic changes, index decomposition analysis [31,32], structural decomposition analysis [33,34], and stochastic regression models based on STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) [11,35]. Carbon intensity is a crucial factor that measures the regional green low-carbon development performance. For instance, Cao and Karplus [6] have found that the carbon emission intensity decreased during the 11th five-year and 12th five-year periods, due to the decline in coal usage in China. Hou et al. [7] have suggested that industrial development was transforming toward a green ecosystem in most Chinese provinces by 2015, and that the environmental pollution was under control, although industrial expansion after the financial crisis resulted in an increased volume of carbon emissions. On the contrary, Fu et al. [36] have documented that China had to choose a coal-dominated energy structure due to constraints, in terms of resource cost and endowment, in the ongoing industrialization process, the solutions to which include decreasing the urbanization process and improving energy efficiency. Wang et al. [37] have demonstrated the homogeneity of carbon-producing efficiency in the major countries along the One Road and One Belt, and suggested some effective approaches to improve it, such as through improving GDP per capita, industrialization efficiency, and broadening openness.

Meanwhile, studies have debated the impact of economic growth and urbanization on carbon intensity, revealing a negative relationship between them [35], while some research has suggested the existence of a non-linear relationship [11]. Manufacturing, as a critical industry, dominates carbon emissions in China; the relevant energy structure may decrease, but this also potentially stimulates carbon emissions [12]. On this basis, some studies have constructed decomposition frameworks to analyze the contributions of technological progress to carbon reductions in China and have documented that it will be the key to energy sustainability [10]. Chen et al. [11] and Zhao et al. [12] have argued that, although investment (as a crucial factor) may increase carbon emissions, improving capital productivity and green investment (i.e., green transition) may effectively decrease carbon emissions.

The green manufacturing transition involves upgrading the petrochemical, steel, and nonferrous metals-dominated heavy industry to high-quality but low-energy consumption and carbon emissions industry, which may decrease carbon intensity [38]. This study proposes three hypotheses, from non-linear, regional heterogeneity, and intermediary mechanism perspectives.

2.1. The Impact of Carbon Emissions on Green Transition

Environmental supervision of the Chinese manufacturing sector requires a gradual carbon reduction; some contamination-dominated manufacturing firms must spend more on purchasing carbon emissions licenses, which decrease their profitability and slow down the green transition in the short term. However, in the long-term, these firms must improve their production capacity and management performance, upgrade the used technology, promote the regional industrial structure, and reduce carbon emissions [39]. Research has shown the existence of an inverted U shape or N shape relationship between carbon intensity and economic development, rather than a linear relationship, in Asian countries [40]. As the manufacturing industry dominates the Chinese economy, such a non-linear relationship should exist between the carbon emissions and the green economy in the Chinese manufacturing sector, as hypothesized below:

Hypothesis H1. *There exists a non-linear relationship between carbon intensity and green transition in the Chinese manufacturing sector.*

2.2. Provincial Heterogeneity

Due to China's unbalanced resource reserve and economic development, each province is different, in terms of carbon intensity, administrative policies, financial performance, and so on. Thus, the carbon intensity affects the green economy differently at the provincial level. Figure 2b shows that the well-developed regions—including Zhejiang, Jiangsu, Guangdong, Shanghai, and Beijing—perform well in terms of carbon reduction, while others do not. Zhang et al. [30] found regional differences in the carbon reduction effect of green financial policies; these policies that improve environmental quality are more efficient in resource-driven regions than in the others, and they argue that the green financial policies should be regionally different. Therefore, we propose the following hypothesis:

Hypothesis H2. *Each province has regional carbon intensity and green manufacturing transition heterogeneity*.

2.3. Intermediary Effect of Financial Performance

Industrial capital in developed countries facilitates the financing of manufacturing firms, easing the financial pressure on banks and providing firms with long-term and stable money. Thus, financial markets should play a vital role in the manufacturing green upgrade in China. He [41] has documented that well-developed financial markets have contributed to the transition in Zhejiang province. Therefore, financial performance drives green promotion, and thus, we propose the following hypothesis:

Hypothesis H3. *Financial performance, as an intermediary effect, may promote manufacturing green upgrading in China.*

3. Research Design and Data

This study uses static and dynamic regression models to investigate the relationship between carbon emissions and green development in the Chinese manufacturing industry. Figure 3 outlines a methodology mind-map. First, this study builds static benchmark regression models 1-2 to test whether there is a linear or non-linear relationship between them. Second, this research adopts a mechanism test to investigate the possible indirect relationship through an intermediary variable (FDev). As the Chinese government gives a range of financial policies to support green development for economic sustainability, green credit can improve China's environmental quality overall through three mechanisms: improving firm performance, promoting firm innovation, and upgrading industrial structure [30]. Thus, it is supposed that there should be an indirect linear relationship between, or a direct linear relationship does not exist at, the early stage of the transition strategy. Third, a robustness test is employed to investigate the relationship. Although firms chase profitable but non-environmentally friendly projects at their early stage because of the high cost of environmental protection, they prefer green development for sustainable growth when they grow up. This research supposes that a threshold effect exists for the green transition and investigates it through Equation (6). Therefore, the relationship between carbon emissions and the green transition is comprehensively investigated.

As the static models do not take the lag effect into account and cannot address the endogeneity between the dependent and independent variables, which should be substantial, this research investigates whether a lag effect exists in the relationship tested by Equation (7).

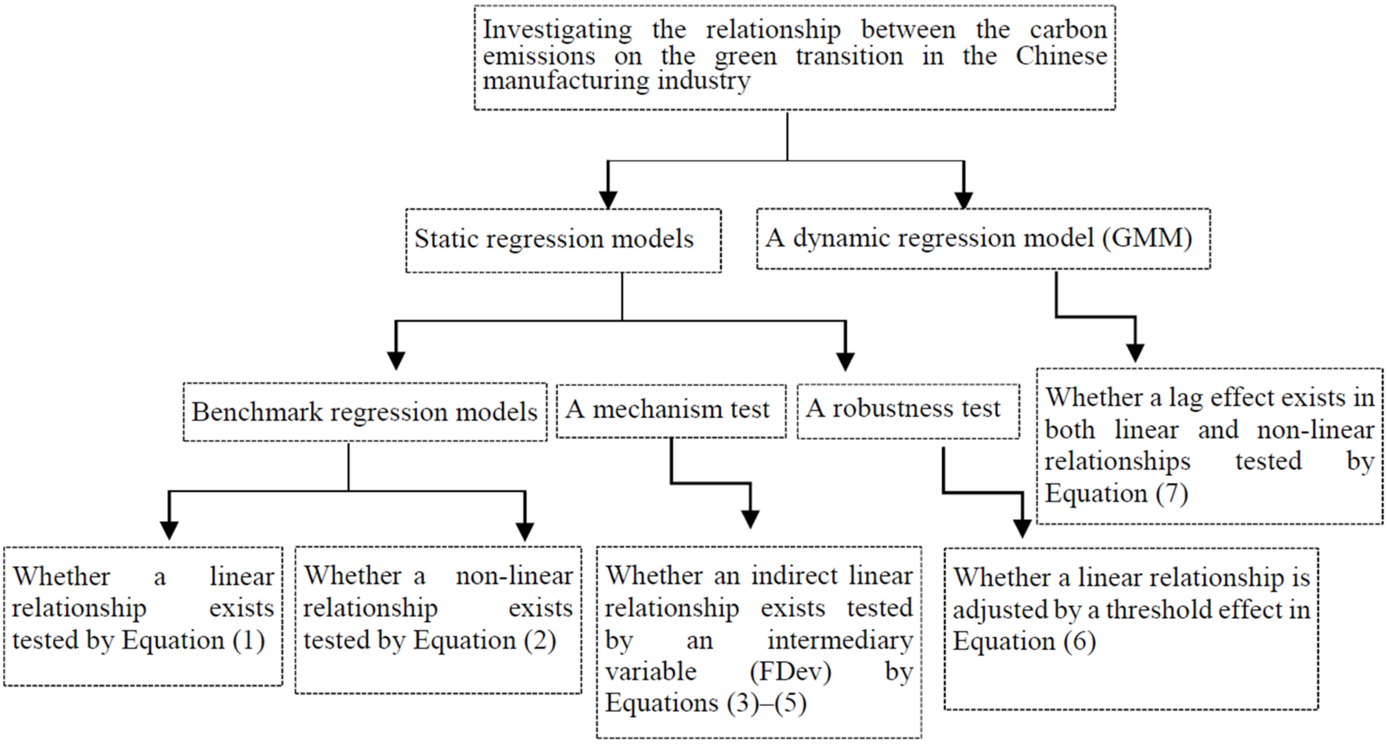


Figure 3. Methodology mind-map.

3.1. Regression Models

3.1.1. Benchmark Regression Models

We take carbon intensity (*CE*) as an independent variable, green upgrade (upgrading) as a dependent variable, and include some control variables (*X*). A basic benchmark regression model was developed, as follows:

$$\text{lnupgrading}_{i,\,t} = \beta_0 + \beta_1 CE_{i,t} + \beta_2 X_{i,t} + u_i + u_t + \varepsilon_{i,t}, \tag{1}$$

where Upgrading$_{i,t}$ denotes the upgrading capacity of a manufacturing firm i in year t, which is measured by its natural logarithm to mitigate heteroscedasticity of the data; $CE_{i,t}$ represents the carbon intensity of a firm i in year t; $X_{i,t}$ denotes a group of control variable values; u_i and u_t refer to the fixed effects of each firm i and in each year t, respectively; and $\varepsilon_{i,t}$ is a random error.

To test the potential non-linear relationship between the dependent and independent variables, we include the binomial variable of carbon intensity ($CE2_{i,t}$), with which the benchmark model was further developed as:

$$\text{lnupgrading}_{i,t} = \beta_0 + \beta_1 CE_{i,t} + \beta_2 CE2_{i,t} + \beta_3 X_{i,t} + u_i + u_t + \varepsilon_{i,t}. \tag{2}$$

If $\beta_2 > 0$, it means there exists a U-shaped relationship between carbon intensity and manufacturing transition; and if $\beta_2 > 0$, there exists an inverted U-shaped relationship.

3.1.2. Mechanism Test Models

The financial industry has developed rapidly and unevenly in China, and the Chinese manufacturing firms rely heavily on financial support to meet carbon reduction targets. It is supposed that financial development (FDev) should play an intermediary role in adjusting the relationship between carbon intensity and green upgrading. The intermediary models are developed below, in order to verify this proposition:

$$\text{lnupgrading}_{i,t} = \beta_0 + \beta_1 CE_{i,t} + \beta_2 X_{i,t} + u_i + u_t + \varepsilon_{i,t}, \tag{3}$$

$$\text{FDev} = \alpha_0 + \alpha_1 CE_{i,t} + \alpha_2 X_{i,t} + u_i + u_t + \varepsilon_{i,t}, \quad (4)$$

$$\text{lnupgrading}_{i,t} = K_0 + K_1 CE_{i,t} + K_2 FDev + K_3 X_{i,t} + u_i + u_t + \varepsilon_{i,t}. \quad (5)$$

3.1.3. Further Test of Threshold Effects

Due to the unbalanced economic development in China, the regional economy underperforms in less urbanized and marketized provinces. At the same time, well-developed regions attract more talents and promote technological innovations, facilitating synergistic development of the environment and the economy [42]. On this basis, a threshold effect is supposed to exist between carbon intensity and green growth. We employed a threshold panel regression model, including marketization and urbanization as independent variables, in order to investigate the threshold effect. The threshold regression model was developed as follows:

$$\text{lnupgrading}_{it} = \beta_0 + \beta_1 CE_{it} * I(thrit \leq \lambda) + \beta_2 CE_{it} * I(thrit \geq \lambda) + \beta_3 X_{it} + u_i + u_t + \varepsilon_{it}, \quad (6)$$

where I is the threshold coefficient, and *thrit* is the threshold value.

3.1.4. Dynamic Test

The benchmark models investigate whether carbon intensity affects the green transition. Additionally, static models do not take the lag effect into account and cannot address the endogeneity between the dependent and independent variables, which may be substantial; it is expected that we should further test the extent of the effect as time passes. The Generalized Method of Moments (GMM) is different from an ordinary panel data model, as it takes the lagged dependent variables into account. Additionally, it measures some individual heterogeneity unobserved in a dynamic panel model and the correlation of the errors of the dynamic panel model. The traditional ordinary least squares and fixed effect models are not able to measure these effective values. Thus, in this study, we use a dynamic panel model (i.e., GMM) to conduct a robustness check on the relationship and its lag effect. The lag effect variable ($\text{lnupgrading}_{i,t-1}$) is included in the dynamic panel model, as follows:

$$\text{lnupgrading}_{i,t} = \beta_0 + \beta_1 \text{lnupgrading}_{i,t-1} + \beta_2 CE_{i,t} + \beta_3 CE2_{i,t} + \beta_4 X_{i,t} + u_i + u_t + \varepsilon_{i,t}. \quad (7)$$

Arellano and Bond [43] have documented that both dynamic GMM (DGMM) and systematic GMM (SGMM) are favorable methods for addressing the endogeneity issue. Blundell and Bond [44] have suggested that the systematic GMM is better, as the GMM potentially leads to information loss from the comparable sample, and variable effects decrease when the period becomes longer. Nevertheless, we employed both methods, in order to account for the endogeneity issue.

3.2. Variables

The dependent variable is defined in terms of manufacturing green upgrading. Following the definition of green transition of Wu et al. [45] and the entropy weight method of Zou et al. [46], we consider nine indices from three major perspectives (manufacturing performance, ecosystem, and green sustainability) to comprehensively measure the dependent variable, green upgrading capacity (see Table 1).

The independent variable is defined in terms of the carbon intensity (CE). Following Wang et al. [47], we measure the carbon intensity for each province j using Equation (8), where the carbon emissions of each province are calculated using Equation (9):

$$CE_{j,t} = Co2_t^j \Big/ Y_{j,t} \quad (8)$$

$$Co2_t^j = k \times \sum\nolimits_{i=1}^{8} E_{i,t}^j \times \delta_{i,t}^j \quad (9)$$

where $Co2$ is the total carbon emissions from province j in year t (ranging from 2008 to 2019), k is the weight ratio of Co_2 to molecular carbon (k = 44/12), $E_{i,t}^{j}$ denotes the consumption volume of fossil fuel i in province j in year t, and $\delta_{i,t}^{j}$ refers to emission coefficient of fossil fuel i in province j in year t. According to the "2006 IPCC National Guide of the Greenhouse Gasses Lists" and "China Energy Statistic Yearbook", carbon emissions mainly derive from eight major fossil fuels.

Table 1. The hierarchical factors of manufacturing green upgrading.

Dependent Variable	First Level	Second Level
Green upgrading	Manufacturing performance	Gross production in manufacturing sector Rate of total assets to employees in manufacturing sector Fiscal revenue per capita on average
	Manufacturing ecosystem	Gross production per volume of waste water discharge Gross production per volume of solid waste discharge The green patient rate
	Green sustainability	The rate of R&D employees to total employees in manufacturing sector The rate of R&D expenditure to total fiscal expenditure The rate of the government expenditure to the national GDP

The control variables include foreign direct investment (FDI), advanced industrial structure (AIS), the intensity of energy structure (EI), green finance index (Gfin), pollution governance (PG), industrial development level (Ileve), technological level (TL), and infrastructure level (IL).

3.3. Data

Panel data from 2008 to 2019 were collected from 30 Chinese provinces, excluding Xizang and Taiwan, where some missing data were completed using the interpolation method. The data on both green upgrading and carbon emissions were collected from "Energy Statistic Yearbooks", "China industrial Statistic Yearbooks" and "China Environment Statistic Yearbooks". The control variable data were gathered from "China Fiscal Statistic Yearbooks", "China Civil Affairs Statistic Yearbooks", "Regional Economic Statistic Yearbooks" and "China Technology Statistic Yearbooks".

4. Results and Analysis

4.1. Regression Results

4.1.1. Descriptive Analysis

Table 2 shows that green transition capacity fluctuated dramatically between 442.836 and 17,674.750, from 2008 to 2019. The vast standard deviation of 3134.759 indicates the remarkable difference in green upgrading capacity among the manufacturing firms. Meanwhile, the carbon intensity of firms fluctuated between 0.792 and 9.340, which indicates that some firms performed well in terms of carbon reduction, while others did not. Additionally, the significant difference in IL, with a standard deviation of 10.492, indicates that some firms possessed strong green awareness to improve their infrastructure level for their green sustainability in the long term, while others did not.

4.1.2. Benchmark Regression Results

The results from columns (1)–(4) in Table 3, tested by OLS, GLS, and FE methods, respectively, demonstrate the existence of negative relationships between the carbon intensity and green upgrading, which means that carbon intensity inhibits green upgrading. In column (2), the negative relationship (−0.308) was more significant than the others. Additionally, the coefficients of CE2 in quadratic models were all greater than 0, indicating a U-shaped relationship between carbon intensity and green transition; that is, when the carbon intensity value is less than the turning point value, carbon intensity restricts green sustainability. In contrast, it will promote green development when its value is greater than the turning point. Differently, an ∩-shaped curve was found to exist in eastern China, as the coefficient of CE2 (−0.031) was less than 0.

Table 2. Descriptive analysis.

Variable	Obs	Mean	Std.	Min	Max
upgrading	360	3266.235	3134.759	442.836	17,674.750
CE	360	2.710	1.626	0.792	9.340
FDI	360	0.023	0.020	0.000	0.108
AIS	360	1.098	0.615	0.519	4.165
EI	360	0.415	0.151	0.073	0.689
urban	360	0.559	0.130	0.336	0.893
Gfin	360	0.169	0.099	0.060	0.692
PG	360	0.014	0.007	0.004	0.038
TL	360	0.376	0.088	0.120	0.526
Ileve	360	0.752	0.243	0.237	1.371
IL	360	8.461	10.492	0.445	49.262
market	360	0.335	0.231	0.035	2.093
FDev	360	0.061	0.031	0.014	0.185

Table 3. Benchmark regression results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	OLS		GLS	FE	Eastern	Central	Western
	Upgrading		Upgrading	Upgrading	Upgrading	Upgrading	Upgrading
CE	−0.255 ***	−0.308 ***	−0.152 **	−0.145 *	0.389	−0.524 ***	−0.163 **
	(−10.989)	(−3.826)	(−2.399)	(−1.790)	(1.495)	(−3.480)	(−2.191)
CE2		0.032 ***	0.011 **	0.014 **	−0.031	0.050 **	0.017 **
		(3.933)	(2.269)	(2.167)	(−1.259)	(2.224)	(2.484)
FDI		1.905	3.110 ***	3.160 ***	−0.554	−1.143	21.827 ***
		(1.193)	(3.300)	(2.699)	(−0.267)	(−0.327)	(4.263)
AIS		−1.042 ***	−0.043	−0.078	0.215	−0.246	−0.788 **
		(−5.849)	(−0.512)	(−0.747)	(0.988)	(−1.394)	(−2.029)
EI		1.054 ***	−0.307	−0.153	−0.380	1.274 ***	−0.236
		(4.501)	(−1.306)	(−0.521)	(−0.413)	(4.735)	(−0.726)
Gfin		8.157 ***	−1.380 **	−0.778	1.064	4.000 **	3.552
		(8.094)	(−2.419)	(−1.061)	(0.856)	(2.199)	(1.399)
PG		−15.260 ***	0.420	−0.546	6.257	−14.539 ***	−3.913
		(−2.839)	(0.192)	(−0.205)	(1.233)	(−2.869)	(−0.642)
TL		−1.817 *	1.302 ***	1.040 **	−0.740	2.220 ***	−3.492 **
		(−1.947)	(3.201)	(2.060)	(−0.716)	(2.778)	(−2.209)
Ileve		0.511 ***	0.391 ***	0.459 ***	1.345 ***	0.271	−1.050 ***
		(3.162)	(4.706)	(4.458)	(5.581)	(1.459)	(−3.975)
IL		0.007	0.003	0.000	−0.003	0.014	0.012
		(1.195)	(1.004)	(0.175)	(−0.591)	(0.874)	(0.576)
_cons	8.433 ***	7.994 ***	6.787 ***	7.471 ***	6.700 ***	6.882 ***	9.841 ***
	(114.843)	(14.624)	(24.441)	(21.495)	(7.874)	(12.361)	(10.148)
Year			Yes	Yes	Yes	Yes	Yes
Province			Yes	Yes	Yes	Yes	Yes
F values			186.810	7.900			
N	360	360	360	360	144	108	108
R^2	0.252	0.587	0.968	0.951	0.928	0.913	0.847

Note: Figures in brackets are t values. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

In summary, carbon intensity increases when the economy improves, while the green transition of the manufacturing firms decreases and then increases. The reason for this is that ongoing innovation and technological updates facilitate carbon reductions, while a range of carbon discharge measurements restrain economic growth [48]. The U-shape indicates that the negative relationship between carbon intensity and green upgrading will become positive. These findings support Hypothesis H1.

4.1.3. Provincial Heterogeneity

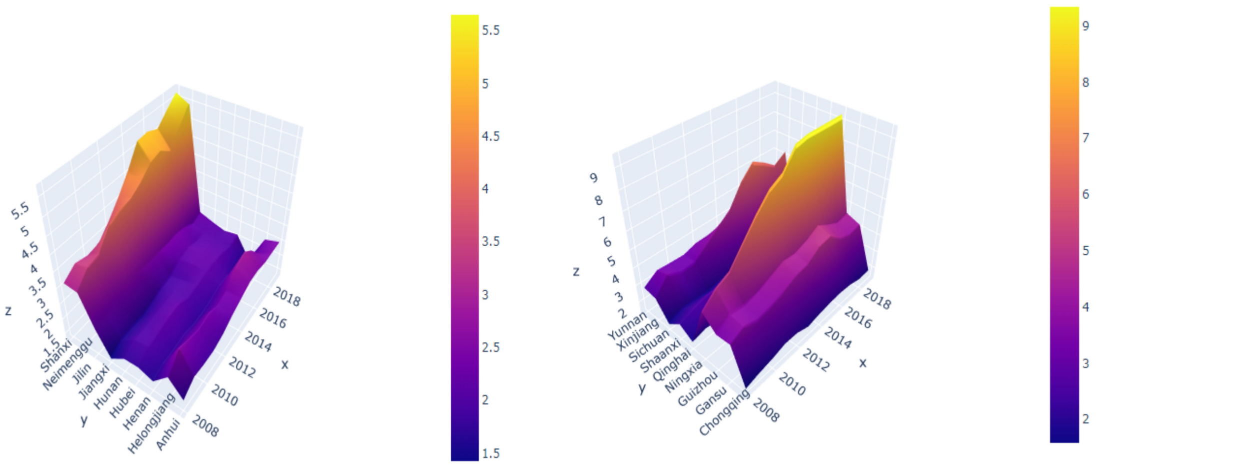
As carbon intensity is closely associated with economic growth, and there exists a dramatic disparity in regional economic performance, industrialization, and natural resources in China, a further study was conducted to investigate the regional heterogeneity of the relationship between carbon intensity and green transition. According to Lu and Yang [49], the 30 Chinese provinces can be grouped into three parts: eastern, central, and western.

The carbon intensity (CE) values in columns (5)–(7) show their respective heterogeneity; in particular, the eastern regions presented different results. The positive coefficient of CE (0.389) indicates higher carbon intensity and green upgrading, due to the inverted U-shaped relationship in this region. Therefore, increasing carbon intensity does not inhibit green development in the area. The initially negative relationship will become positive in the particular circumstance where carbon intensity increases beyond the turning point.

This upgrading can possibly be attributed to other contributors, such as comparable innovation capability and technical advantages for the green transition. For instance, Liaoning and Shanghai possess more energy conservation and green innovation advantages to deal with their growing energy consumption and industrial contaminants [7].

In contrast, increasing carbon intensity restrains green development in the central and western provinces of China, considering the negative relationships in columns (6) and (7). The carbon intensity had the most significant impact (−0.524) in central China. Furthermore, the coefficient (21.827) of FDI indicated that the western Chinese provinces significantly rely on investments to facilitate their green economy, while the eastern and central regions do not. These different findings support Hypothesis H2; that is, a regional heterogeneity exists for each province, in terms of carbon intensity and manufacturing green transition.

Figure 4 shows the three-dimensional carbon intensity distribution in some provinces, which was calculated using Jupyter Notebook software. The x-axis denotes years, the y-axis represents the provinces, and the z-axis shows the manufacturing carbon intensity values. Figure 4a shows the carbon intensity distributions in the central areas of China. Shanxi and Neimenggu overwhelmingly dominated, in terms of carbon emissions in the region, in 2008, and increased significantly in the following years. On the contrary, Jiangxi, Henan, and Anhui performed well, in terms of carbon reductions, and maintained low carbon intensity over the next ten years, as these provinces have guided their manufacturing firms to develop toward technology-oriented and capital-based industries since 2009 [50]. Thus, they had more capital and advanced technologies, investment into carbon reduction and business growth, and balanced the relationship between carbon reduction and green sustainability.



(**a**) (**b**)

Figure 4. The distribution of the manufacturing carbon intensity in central (**a**) and western (**b**) provinces of China.

Additionally, Figure 4b indicates the carbon intensity distributions in western Chinese provinces. Ningxia initially had the highest carbon emissions, which increased dramatically in the following years, followed by Guizhou and Gansu. By contrast, Chongqing, Qinghai, and Sichuan had lower emissions, which they maintained in the following years. Therefore, the green transition increased while the carbon intensity grew in some provinces but decreased in others. These results further support Hypothesis H2.

4.2. Mechanism Test Results

Column (2) in Table 4 indicates that a U-shaped relationship also exists between carbon intensity and financial development, as the coefficient of CE2 (0.001) is greater than 0. Therefore, the carbon intensity initially restrains financial growth and then promotes it after the turning point. This result is in line with that examined by the GMM method in column (5). This can be partially attributed to two reasons: the left side of the "U" shape refers to the early development stage of manufacturing firms; these firms, with high carbon emissions, have little access to financial support. When these firms mature and come to the right side, they become strong, with more carbon emissions, and have more access to financial resources.

Table 4. Mechanism test results from the intermediary models.

	(1)	(2)	(3)	(4)	(5)	(6)
	FE Upgrading	**FDev**	**Upgrading**	**GMM Upgrading**	**FDev**	**Upgrading**
CE	−0.547 ***	−0.009 ***	−0.630 ***	−0.087 ***	−0.006 ***	−0.095 ***
	(−8.540)	(−3.511)	(−10.376)	(−3.121)	(3.556)	(9.787)
CE2	0.047 ***	0.001 ***	0.056 ***	0.010 ***	0.001 ***	0.011 ***
	(7.421)	(3.978)	(9.331)			(3.863)
FDev			−9.498 ***			−1.093 *
			(−7.280)			(−1.812)
$upgrading_{-1}$				0.939 ***	−0.005 ***	0.934 ***
				(52.113)	(−9.003)	(51.181)
FDI	4.182 ***	0.011	4.283 ***	0.040	0.020	0.053
	(3.387)	(0.222)	(3.726)	(0.074)	(1.264)	(0.099)
AIS	−0.739 ***	0.023 ***	−0.521 ***	−0.110 *	0.010 ***	−0.098
	(−5.267)	(4.223)	(−3.885)	(−1.727)	(5.368)	(−1.525)
EI	0.937 ***	0.025 ***	1.175 ***	0.120	0.047 ***	0.158 *
	(5.189)	(3.571)	(6.859)	(1.396)	(17.630)	(1.787)
Gfin	5.083 ***	0.029	5.355 ***	0.693 *	0.100 ***	0.805 **
	(6.307)	(0.917)	(7.128)	(1.951)	(9.538)	(2.238)
PG	−2.590	0.403 **	1.239	0.041	0.150 ***	0.207
	(−0.604)	(2.424)	(0.308)	(0.023)	(2.880)	(0.116)
TL	0.171	−0.023	−0.042	−0.351	−0.088 ***	−0.434
	(0.228)	(−0.773)	(−0.061)	(−1.068)	(−8.928)	(−1.312)
Ileve	−0.575 ***	−0.007	−0.641 ***	0.015	0.007 ***	0.023
	(−3.908)	(−1.226)	(−4.673)	(0.266)	(3.999)	(0.414)
IL	−0.015 ***	0.001 ***	−0.008 *	−0.004 *	0.001 ***	−0.003
	(−2.905)	(3.445)	(−1.726)	(−1.951)	(18.414)	(−1.418)
_cons	8.753 ***	0.037 **	9.107 ***	0.826 ***	0.079 ***	0.915 ***
	(19.840)	(2.173)	(22.018)	(3.319)	(10.266)	(3.615)
N	360	360	360	330	330	330
AR(1)				0.000	0.000	0.000
AR(2)				0.130	0.165	0.135
Sargan				0.181	0.000	0.183

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

The coefficients of FDev (−9.498 and −1.093) in columns (3) and (6) demonstrate the existence of a negative relationship between financial development and green upgrading.

Therefore, financial development plays an intermediary role and restrains a firm's green growth. These findings reject Hypothesis H3.

In China, manufacturing firms have more access to financial resources when the financial system develops, which reduces their financial costs. Then, they invest in extending their business for more profits. Meanwhile, more carbon emissions are generated, and as a result, the green transition underperforms.

The results provided in Table 5 show that both marketization and urbanization have threshold effects on carbon intensity. Urbanization has a more significant threshold effect than marketization, which means that marketization may serve as a more practical approach to adjust the relationship between carbon intensity and green transition.

Table 5. Threshold effect test of urbanization and marketization on carbon intensity.

Variables	Single Threshold Model	
	Statistic Values	F Values
Urbanization	I = 0.580	57.790 *** (0.004)
Marketization	I = 0.321	50.080 *** (0.002)

Note: The figures in brackets are the *p* values calculated by the Bootstrap method. *** denotes significance at 10% level.

The coefficients (-0.005, -0.017) of CE2 in Table 6 are greater than 0, indicating an inverted U-shaped relationship between carbon intensity and green upgrading. The CE coefficients ($I \leq \lambda$; $I > \lambda$) demonstrate the significant threshold effects on the relationship between carbon intensity and the green transition. The carbon intensity improves the green transition on both sides of the threshold point. Nevertheless, the contribution is more significant on the right side ($I > \lambda$).

The threshold was 0.58, as shown in Table 5. Therefore, before the urbanization level reaches 0.58, the carbon emissions intensity is significantly positive for the green transition of the manufacturing industry. When the urbanization level exceeds 0.58, the carbon emissions intensity coefficient increases significantly, promoting the positive effect of carbon emissions on the green transition of the manufacturing industry. A region's urbanization level affects and determines its development stage and industrial structure, to a certain extent. A higher level of urbanization brings better human capital accumulation and a higher degree of trade openness, while the economic development model becomes more mature. All of these factors play a positive role in improving the total factor productivity of manufacturing enterprises. The fundamental law of transition and upgrading of the manufacturing industry from labor- and capital-intensive to technology-intensive is that when urbanization reaches a certain level, the proportion of the manufacturing industry continues to rise. In contrast, the service industry develops rapidly, and the manufacturing industry begins to transition into the service sector. Under the control of other variables, urbanization in China can effectively promote regions to speed up their high-tech development and, thus, attract foreign and government investment, combined with green development policies to guide the green transition of manufacturing.

In the case of the market as the threshold, the carbon emissions intensity and the green transition present an inverted U-shaped curve with a threshold value of 0.321. Therefore, before the marketization level reaches 0.321, the carbon emissions intensity is significantly positive for the green transition of the manufacturing industry. When the urbanization level exceeds 0.321, the carbon intensity coefficient increases significantly, promoting the positive role of carbon emissions on the green transition of the manufacturing industry.

Table 6. Threshold effects of urbanization and marketization on the relationship between carbon intensity and green upgrading.

Variables	**(1)**	**(2)**
	Upgrading	**Upgrading**
CE(I ≤ λ)	0.157 *	0.265 ***
	(1.902)	(3.200)
CE(I > λ)	0.245 ***	0.336 ***
	(2.974)	(3.974)
CE2	−0.005	−0.017 **
	(−0.674)	(−2.386)
FDI	1.442	1.523
	(1.083)	(1.140)
AIS	−0.002	0.092
	(−0.020)	(0.809)
EI	−1.898 ***	−1.527 ***
	(−6.443)	(−5.104)
Gfin	3.302 ***	3.109 ***
	(4.558)	(4.271)
PG	−1.725	−1.070
	(−0.581)	(−0.359)
TL	−0.017	0.109
	(−0.032)	(0.204)
Ileve	0.814 ***	0.740 ***
	(7.455)	(6.860)
IL	−0.005	−0.004
	(−1.162)	(−0.847)
_cons	6.957 ***	6.546 ***
	(19.800)	(18.418)
N	360	360
R^2	0.738	0.736

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

The deepening of the marketization process is the most representative microcosm of China's economic reform and is essential to promote the upgrading of Chinese manufacturing industries. The increasing regulatory role of the market environment can weaken the promotion of industrial upgrading, by affecting the ability of enterprises to dispatch and raise resources, as well as optimizing the function of innovation funds in promoting industrial upgrading. Meanwhile, effectively promoting the proportion of green loans in China's financial market, reducing the transaction costs of multi-national enterprises and improving the execution efficiency of financial contracts also promote the manufacturing industry to meet the development needs of emerging enterprises, thus deepening the green transition and upgrading.

4.3. Dynamic Test Results

The dynamic model results further demonstrate how much the relationships changed when compared with previous years. The coefficients of upgrading$_{t-1}$, calculated by different methods in columns (2)–(5) in Table 7, indicate a significant lag effect. In particular, when using the SGMM method (column 5), the lag coefficient was 0.939; that is, in this case, the current carbon intensity will positively impact the green upgrading in the next year.

Additionally, the robustness results for the dynamic model are consistent with the findings in Table 3. A negative relationship and a U-shaped relationship between carbon intensity and green development are determined by each method, confirming that, at present, the relationship moves along the left side of the U shape, and does not go past the turning point. Accordingly, carbon reductions restrain the green development of the Chinese manufacturing firms; however, they will have a promoting effect past the turning point. This is possible, as the current carbon intensity has not remained sustainable and the manufacturing firms have not maximized the compensatory effects of innovations, thus restraining green development [51].

Table 7. Robustness test results for the dynamic model.

Variables	(1)	(2)	(3)	(4)	(5)
	FE		GLS	DGMM	SGMM
	Upgrading	Upgrading	Upgrading	Upgrading	Upgrading
CE	−0.145 *	−0.126 *	−0.125 **	−0.299 *	−0.087 ***
	(−1.790)	(−1.941)	(−2.116)	(−1.778)	(−3.121)
CE2	0.014 **	0.014 ***	0.012 **	0.032 *	0.010 ***
	(2.167)	(2.656)	(2.526)	(1.941)	(3.556)
$upgrading_{t-1}$		0.862 ***	0.652 ***	0.835 ***	0.939 ***
		(19.775)	(10.811)	(7.673)	(52.113)
FDI	3.160 ***	1.254	1.375	2.961	0.040
	(2.699)	(1.255)	(1.554)	(1.058)	(0.074)
AIS	−0.078	−0.032	0.016	−0.027	−0.110 *
	(−0.747)	(−0.372)	(0.209)	(−0.146)	(−1.727)
EI	−0.153	−0.150	−0.012	−0.556	0.120
	(−0.521)	(−0.645)	(−0.054)	(−1.558)	(1.396)
Gfin	−0.778	0.632	−0.306	1.246	0.693 *
	(−1.061)	(1.156)	(−0.577)	(1.018)	(1.951)
PG	−0.546	0.797	0.339	4.757 *	0.041
	(−0.205)	(0.364)	(0.171)	(1.985)	(0.023)
TL	1.040 **	−0.230	0.382	−0.125	−0.351
	(2.060)	(−0.559)	(0.983)	(−0.123)	(−1.068)
Ileve	0.459 ***	−0.003	0.146 *	−0.141	0.015
	(4.458)	(−0.039)	(1.858)	(−0.711)	(0.266)
IL	0.001	−0.002	0.000	−0.004	−0.004 *
	(0.175)	(−0.612)	(0.129)	(−0.637)	(−1.951)
_cons	7.471 ***	1.424 ***	2.544 ***		0.826 ***
	(21.495)	(3.481)	(5.090)		(3.319)
Year	Yes	Yes	Yes		
Province	YES	Yes	Yes		
F value	7.900	145.320	227.190		
AR (1)				0.046	0.000
AR (2)				0.230	0.130
Sargan				–	0.181
Hansen test				1.000	–
N	360	330	330	300	330
R^2	0.951	0.966	0.976		

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Furthermore, investment is a promising approach for manufacturing firms, in terms of driving their green development, while infrastructure level is insignificant. These findings are in line with those in Table 3.

To sum up, carbon intensity has spillover effects on a firm's innovation inputs, and the marginal cost of carbon reduction at the beginning is much higher than at any other stage; the manufacturing firms have no motivation to reduce carbon intensity and improve green upgrading. Nevertheless, the manufacturing firms have to pursue technological innovation and carbon reduction to maintain their sustainable development in the long run.

5. Discussion

We observed a U-shaped relationship between carbon intensity and manufacturing green transition; specifically, the carbon intensity restrains the green growth and then promotes it. Furthermore, the transition performance at every stage may contribute to that in the next stage. We found that the green transition turning point of the predominant manufacturing industry was around 5.18 CE. Although this transition facilitates industrial carbon reduction and decreases industrial energy consumption, it also decreases industrial growth. Similarly, Lin et al. [52] have demonstrated that the carbon intensity per capita in China changed from negative to positive after 2002. Therefore, China is facing a significant challenge in balancing the relationship between carbon emissions and the green transition, as it is in the growing process and developing toward a high-quality economy. With this finding, the policymakers should release appropriate carbon reduction policies according to the firms' growing status, after the turning point of the U-shape, encouraging the manufacturing firms to transform from an environment-based to an innovation-dominated development model.

In addition, we observed the most substantial spatial effects of carbon intensity on the green manufacturing transition in the central provinces, followed by the eastern provinces, potentially due to the difference in regional industrial structures. The central provinces are driven by emerging industries, such as IT, biomedical engineering, and the electronics sector, which attract more advanced technologies that promote the green transition. In the western provinces, the underdeveloped economy relies on traditional energy consumption, instead of new clean energies, resulting in higher carbon emissions than in other areas. Thus, at present, the green transition is restricted in the western provinces, the local governments in the regions are suggested to take advantage of natural resources to develop renewable energies, and the carbon reduction policies should vary according to the different regional economic performance.

Moreover, the results suggested that financial performance is negatively associated with the green transition, as more capital flows into contamination-dominated but profitable projects, thus inhibiting growth. However, some studies have documented that financial development is crucial for the manufacturing transition and upgrade, as it may facilitate transition cost reduction and promote technological progress; however, these studies have focused on specific regions or provinces with sound financing environments [53,54], while not including the green factor. The Chinese financial system is under-developed, and green loans amount to less than others. The majority of manufacturing firms invest their money in high-energy but profitable projects. This fact accounts for the observed negative relationship. Furthermore, urbanization and marketization contribute to the green transition, as both strategies promote economic growth that attracts more investments, facilitating industrial transition and upgrading. This finding has been supported by Li et al. [55].

This study has various implications. First, some recycling, low-carbon, and ecological options may facilitate upgrading China's manufacturing industry to achieve green development. In this context, there is still ample space for growth. Chinese manufacturing firms have been facing problems associated with short product life-cycles, long equipment upgrade cycles, and increasing complexity. The green promotion effect will be inefficient if these problems cannot be solved effectively. Thus, the manufacturing industry has to adjust and reform its industrial structure, product R&D, and production organization modes. Considering the characteristics of time lag, we should cooperate with China's green transition policy, improve the environmental mechanisms of local governments, speed up the transition of government functions, and pay equal attention to rewards and punishments for ecological performance. This paper provides a basis for improving the carbon emissions capacity of the manufacturing industry, which can be achieved by developing high-tech industries, optimizing the financial structure, improving the level of green finance, improving market efficiency, and promoting the development of Chinese cities and towns.

Second, regional coordinated development must be facilitated. Our results demonstrated that carbon emissions have regional heterogeneity in manufacturing. The green transition of China's manufacturing industry in the future must involve the breakthrough of the whole country (instead of mainly the developed provinces and cities in North China) to the world's manufacturing frontier technology, vigorously developing high-tech industries, and advanced manufacturing and other emerging industries, while accelerating the pace of green transition of manufacturing in various regions. This should fully meet the need for regional development, instead of only providing substantial support for North China to advance in the world's high-end manufacturing. It is crucial to support the harmonious development of China's manufacturing industry among all regions, provinces, and cities, thus achieving coordinated transition and upgrading.

Third, government involvement is recommended. Although the Chinese government has implemented a range of carbon-reduction policies encouraging development toward a green and recyclable economy and promoting green transition in the manufacturing industry, manufacturing firms prefer to make investments to increase their productivity and expand their production scale. Under the circumstances of development priority, the government should encourage investments for energy-saving and carbon-reduction purposes. Therefore, the government should become involved through fiscal and tax policies, such as tax incentives for clean energy, low-interest loans for green transitions, and carbon tag institutions to promote manufacturing firms to care about R&D into energy-saving technologies and the green upgrading of equipment.

Finally, green finance development should match the growth of the manufacturing industry. China must improve its financial structure and accelerate the marketization process, which will promote the transition of China's manufacturing sector. Under the circumstances of strengthening the market mechanism, the ability of all enterprises to raise resources, and the efficiency of capital allocation, the comparative advantage of manufacturing enterprises in raising resources will be strengthened. The innovation funds of enterprises will be more efficient in use, promoting high-tech development in the manufacturing industry from labor- and capital-intensive to technology-intensive, which will have a positive role in promoting industrial green upgrading. Meanwhile, other options may also be suggested, such as optimizing other manufacturing industrial structures through economic and executive approaches, encouraging mergers and acquisitions toward large-scale structures, shutting down high-carbon emission sectors, and upgrading the industrial model to advanced and low-carbon structures.

6. Conclusions

Using data from 30 Chinese provinces and cities, we employed an entropy weight method to assess the green transition capacity of manufacturing firms and employed FE and GLS regression models to investigate the relationship between carbon intensity and green upgrading with respect to these firms. We also adopted a dynamic panel model to further investigate this relationship including the lag effects of green upgrading. Furthermore, financial development was included in an intermediary model, in order to explore the mechanism of its impact on the relationship between carbon intensity and the green transition. Finally, marketization and urbanization threshold effects on the green transition were discussed. This study revealed some significant findings, detailed as follows.

First, both the green transition of the manufacturing industry and the overall CE increase steadily. Second, CE presented a significant U-shaped effect on the manufacturing industry's green growth, where the carbon emissions intensity first inhibits and then promotes the green transition. Additionally, the green transition capacity of the manufacturing industry is affected by lag effects. At present, the Chinese manufacturing green transition is on the left side of the U-shaped curve, likely because its current carbon emissions are not at a reasonable level. The initial growth of manufacturing enterprises failed to promote the "innovation compensation effect" and, beyond the "Bode point", showed a trend of slow progress in the manufacturing green transition with an increase in carbon emissions intensity.

Third, from the regional perspective, the impact of carbon emissions intensity on the green transition of the manufacturing industry was the strongest in the central region, followed by the western part. In addition, China's financial development level is seriously unbalanced, and the development of green credit is slow. Therefore, financial products can promote the improvement of financial status by enhancing this mechanism, resulting in reduced financing costs for most enterprises in the province, subsequently stimulating enterprises to expand production. However, most manufacturing firms intend to allocate more funds to high-pollution, high-return projects, due to the potentially high returns, thus reducing manufacturing green transition capacity and, consequently, inhibiting green development.

Finally, further extension of the study indicated that the market environment and urbanization play positive roles in promoting the green transition of the manufacturing industry and accelerating the reduction of carbon emissions, which is of great significance in promoting the green growth of China's manufacturing sector.

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