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Original Paper

Inter-Provincial Differences and Influencing Factors of Carbon Information Disclosure in China: Empirical Evidence from Listed Firms in Low-Carbon Pilot Provinces and Cities

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Abstract

With the increasing global warming and rising sea levels, reducing carbon emissions has become an important concern for countries around the world. China has been committed to actively addressing global climate change for many years and has introduced a series of policies, including low-carbon pilot provinces and cities, to promote emissions reduction in various regions and industries. This study takes A-share listed firms from ten provincial-level administrative regions in China's low-carbon pilot provinces and cities as samples, analyzes the spatiotemporal distribution of carbon information disclosure quality of firms in various regions and industries in China from 2015 to 2019, and uses a multiple regression model to analyze the differences in influencing factors of carbon information disclosure quality among firms in different regions. The study finds that the quality of carbon information disclosure by firms in China has been improving year by year, but the overall disclosure quality is still low. There is generally less disclosure of climate change-related risks, opportunities and actions, and GHG emissions accounting. In addition, human capital intensive industries with relatively less direct carbon emissions also have lower carbon information disclosure quality. Moreover, there are regional differences in the quality and influencing factors of carbon information disclosure by firms in China. The carbon information disclosure quality of firms in the east coastal area of China is relatively higher than that of firms in the central and western China. Some influencing factors in existing literature have a significant impact on the quality of carbon information disclosure by firms in the east coastal area of China, but have no significant impact on the quality of carbon information disclosure by firms in the central and western China. This study not only enriches the relevant research and theory of carbon information disclosure by firms, but also helps the government and firms promote carbon information disclosure through policy formulation and optimization of corporate governance structure.

Keywords

carbon information disclosure, carbon emissions, inter-provincial differences, low-carbon pilot provinces and cities

1. Introduction

In recent years, extreme weather and natural disasters caused by global warming have increased. The most important cause of global warming is the emissions of carbon dioxide and other greenhouse gases (GHG). Therefore, reducing carbon emissions has become an important way to solve global warming, and it has also become the focus of attention of countries around the world. In December 2015, the Paris Agreement, which is of historic significance for mankind's response to climate change, was adopted at the 21st United Nations Climate Change Conference. The Paris Agreement is the second legally binding climate agreement after the Kyoto Protocol. The long-term goal of the Paris Agreement is to limit global warming to well below 2℃, preferably to 1.5℃, compared to pre-industrial levels (Rogelj et al., 2016). To achieve this long-term goal, signatory nations aim to peak GHG emissions as soon as possible and achieve net-zero GHG emissions in the second half of this century.

As the largest developing country and the largest carbon emitter, China is actively making unremitting efforts to fight against climate change. At the 2015 Paris Summit, China committed to reducing its carbon intensity by 60%-65% by 2030 compared with its 2005 level (Feng et al., 2021). At the general debate of the 75th session of the UN General Assembly on 22 September 2020, China committed to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. These commitments have brought enormous pressure and challenges to China's energy conservation and emission reduction efforts. In order to promote the implementation of China's goal of controlling GHG emissions, China has introduced a series of low-carbon policies, such as low-carbon pilot policies. In 2010, China identified five provinces of Guangdong, Liaoning, Hubei, Shaanxi, and Yunnan and eight cities of Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, and Baoding as the first batch of low-carbon pilot provinces and cities. In 2012, China identified 29 provinces and cities including Hainan, Beijing, and Shanghai as the second batch of low-carbon pilot provinces and cities. In 2017, China identified another 45 cities as the third batch of low-carbon pilot cities.

Firms, especially those in heavily polluting industries, are an important source of carbon emissions. With the increasing public attention to the issue of climate change, firms are prompted to adopt strategies that are conducive to environmental protection to achieve the global goal of reducing GHG emissions (Dutta & Dutt, 2020). In the context of China's efforts to achieve carbon peaking and carbon neutrality goals as scheduled, firms in China should do a good job in the management of carbon emissions and carbon information disclosure. Carbon information disclosure can not only alleviate information asymmetry, help investors in the capital market to analyze and price climate change risks, but also help the government and the public to supervise the carbon management behavior of firms. Under the trend of mandatory disclosure of ESG (Environmental, Social, and Governance) information by firms in China, improving the quality of firms' carbon information disclosure can force firms to actively respond to climate change and enable firms to develop in a green, low-carbon and high-quality pattern.

Research on the influencing factors of firms' carbon information disclosure is mainly concentrated in two aspects. The first is that research focuses on the external influencing factors of carbon information disclosure, including the country (Freedman & Jaggi, 2011), economic growth (Elsayih et al., 2025), industry (Peng et al., 2015), government regulation (Liu et al., 2017; He et al., 2021a), green finance (Zhen & Lu, 2024), institutional pressure (Comyns, 2016), the pressure of stakeholders (Chithambo et al., 2020; Song & Xian, 2024), the pressure of NGOs (Haque & Islam, 2015), culture (Luo & Tang, 2016; He et al., 2021b), media coverage (Berthelot & Robert, 2011; Li et al., 2017), and environmental

certification (Amran et al., 2014). The other aspect of the research focuses on the internal influencing factors of carbon information disclosure, including government ownership (Giannarakis et al., 2018), institutional ownership (Cohen et al., 2023), board effectiveness (Ben-Amar et al., 2015), environmental committee (Berthelot & Robert, 2011), independent directors (Jaggi et al., 2018), professor directors (He et al., 2021b), female directors (Hollindale et al., 2019; He et al., 2021c; Abbasi et al., 2024), CEO duality (Amran et al., 2014), executive overconfidence (He et al., 2021a), gender diversity in top management (Caby et al., 2024), CEO compensation mechanisms (Park et al., 2023), managers' ability (Lee et al., 2023), environmental management accounting (Qian et al., 2018), firm size (Kouloukoui et al., 2019), corporate digital transformation (Chen et al., 2024). The academic interest in firms' carbon information disclosure is increasing but few studies have explored its influencing factors from a spatial perspective. Using a sample of Chinese listed firms in low-carbon pilot provinces and cities, this study explores the inter-provincial differences in the quality of carbon information disclosure of firms and their influencing factors in China.

This study makes the following contributions to the existing literature. First, to the best of our knowledge, this study is the first to investigate the inter-provincial differences in the quality of firms' carbon information disclosure across low-carbon pilot provinces and cities in China. As the largest carbon emitter and developing country, on average, the carbon emissions of a province in China are similar to those of an EU country. There are big differences in the carbon emissions of firms in different provinces in China, so there may be big differences in the quality and the influencing factors of firms' carbon information disclosure in different provinces. Most of the existing literature on the influencing factors of firms' carbon information disclosure in China does not consider the inter-provincial differences in the quality of carbon information disclosure, which leads to inconsistent conclusions on some influencing factors to a certain extent. This study finds that there are obvious inter-provincial differences in the quality of firms' carbon information disclosure in China, and the same influencing factor also has different effects in different provinces.

Second, this study complements the extant studies on the influencing factors of firms' carbon information disclosure. Extant studies have investigated various external and internal influencing factors of firms' carbon information disclosure, but there is little evidence of the influencing factors related to the province where the firm is located. This study finds that whether the province where the firm is located belongs to the east coastal area of China and the per capita GDP of that province have a positive impact on the quality of firms' carbon information disclosure.

Third, focusing on the Chinese context, this study can better investigate the impact of geographic location and economic development level in different regions of a country on the quality of carbon information disclosure by local firms. China has a vast territory and unbalanced regional economic development. Using the data from firms in low-carbon pilot provinces and cities in China, this study can explore the spatial differences and influencing factors of firms' carbon information disclosure quality under China's low-carbon pilot policy. The results of this study can provide theoretical basis and empirical evidence for local governments to formulate green and low carbon policies.

The other parts of this article are arranged as follows. Section 2 reviews the relevant literature. Section 3 discusses the empirical research design. Section 4 presents the analysis of the empirical results. Section 5 presents the conclusions, implications, and limitations.

2. Literature Review

The quality of firms' carbon information disclosure has only attracted academic attention for over a decade. The current carbon information disclosure framework has not formed a unified standard, and carbon information disclosure is voluntary in many countries, this leads to a lack of unified standard when evaluating the quality of carbon information disclosure. The existing methods for evaluating the quality of carbon information disclosure are mainly divided into two categories: one is to evaluate directly based on the scores of CDP questionnaires answering by firms (Kumar & Firoz, 2018; Hsueh, 2019). This method is mostly used in studies based on firms in developed countries. For evaluating the quality of carbon information disclosure by firms in developing countries with relatively low proportion of participating in the CDP questionnaire, this method has limitations. The other is to establish an evaluation index, use the content analysis to analyze firms' annual reports, corporate social responsibility reports, and environmental reports or ESG reports, and then score the quality of carbon information disclosure (Choi et al., 2013; Peng et al., 2015; Hummel & Schlick, 2016; Qian & Schaltegger, 2017). This method is widely used by scholars.

In existing literature, scholars have mainly studied the impact of external environmental factors such as the country and industry where the firm is located, as well as internal factors such as firm size, financial leverage, and corporate governance, on the quality of carbon information disclosure. Existing research shows that the quality of carbon information disclosure by firms in Kyoto Protocol signatories is higher than those in non-Kyoto Protocol signatories (Freedman & Jaggi, 2011). The higher the economic growth of a country, the higher the quality of firms' carbon information disclosure in that country (Elsayih et al., 2025). Compared with firms in other industries, firms in high carbon emission industries and heavily polluting industries have higher carbon information disclosure quality (Peng et al., 2015).

In addition to national and industry factors, scholars also investigated the impact of external environmental factors such as government regulation, stakeholder pressure, media coverage, and culture on carbon information disclosure. Existing studies show that pressure from shareholders, governments, NGOs, media and institutional investors can motivate firms to improve the quality of carbon information disclosure (Chithambo et al., 2020; Haque & Islam, 2015; Luo et al., 2012; Reid & Toffel, 2009). Regulatory policies can improve the quality of carbon information disclosure by Australian state-owned enterprises (Liu et al., 2017). Government regulation has also a significantly positive impact on the quality of carbon information disclosure by firms in China (He et al., 2021a). Media coverage can promote the carbon information disclosure of firms (Li et al., 2018), and the quality of carbon information disclosure by firms that have obtained environment certification is higher (Amran et al., 2014). Confucianism, as the cornerstone of traditional Chinese culture, positively affects the quality of carbon information disclosure of firms in China (He et al., 2021b).

In addition, scholars have also investigated the impact of internal factors such as corporate governance and firms' characteristics on carbon information disclosure. Existing research shows that the effectiveness of the board of directors is positively related to the quality of carbon information disclosure (Ben-Amar et al., 2015). When there is an environmental committee on the board of directors, the quality of carbon information disclosure is relatively high (Berthelot & Robert, 2011). The separation of the CEO-board chair role will increase firm's carbon information disclosure (Amran et al., 2014). Independent directors are positively correlated with the quality of carbon information disclosure (Jaggi et al., 2018), and professor directors can improve the quality of carbon information disclosure (He et al., 2021b). The positive correlation (Hollindale et al., 2019; He et al., 2021c),

negative correlation (Amran et al., 2014), and no correlation (Kilic & Kuzey, 2019) between female directors and the quality of carbon information disclosure are supported by empirical results in studies based on firms in different countries. Firms that employ executive compensation schemes that links CEO pay to CSR performance and carbon emissions targets, and firms with high-ability managers are more likely to disclose carbon information (Park et al., 2023; Lee et al., 2023). Existing studies find that the characteristics of firms also have an impact on carbon information disclosure. For example, there is a significant inverted U-shaped relationship between the level of firm digital transformation and the quality of carbon information disclosure (Chen et al., 2024). Firm size is usually positively correlated with the level of carbon information disclosure (Freedman & Jaggi, 2011; Kouloukoui et al., 2019; Eletheriadis & Anagnostopoulou, 2015).

Although research on the evaluation and influencing factors of the quality of firms' carbon information disclosure has been increasing in recent years, few studies have explored the quality of carbon information disclosure from a spatial perspective. Existing studies provide little empirical evidence on the differences in firms' carbon information disclosure quality and their influencing factors among different regions of a country. Using a sample of listed firms in low-carbon pilot provinces and cities in China, this paper explores the inter-provincial differences and influencing factors of carbon information disclosure quality in China.

3. Data and Methodology

3.1 Sample and Data Sources

This study takes A-share listed firms from ten provincial-level administrative regions in China's low-carbon pilot provinces and cities from 2015 to 2019 as research sample. The ten provincial-level administrative regions cover six provinces including Guangdong, Liaoning, Hubei, Shaanxi, Yunnan, and Hainan, and four municipalities including Tianjin, Chongqing, Beijing, and Shanghai. The above ten provincial-level administrative regions are located in the south, northeast, middle, northwest, southwest, north and east of China. The carbon information disclosure quality of firms in the above provincial-level administrative regions can comprehensively reflect the regional distribution of carbon information disclosure quality of firms in China.

The sample period starts in 2015 because carbon information disclosure did not receive sufficient attention from listed firms in China and listed firms disclosed relatively little carbon information before that year. Starting from 2015, the Chinese government began to implement the "Measures for Disclosure of Environmental Information in Enterprises and Institutions" and the new "Environmental Protection Law", gradually improving the environmental information disclosure system for listed firms. Considering the impact of the pandemic, the sample period ends in 2019. From 2020 to 2022, many Chinese firms faced the dilemma of financial strain and insufficient demand. Many firms were forced to postpone or cancel their originally planned carbon information disclosure projects, which affected the timeliness and completeness of information disclosure and affected the progress and quality of carbon information disclosure. Therefore, the carbon information disclosed by firms during the three-year pandemic period cannot objectively and comprehensively reflect the quality and development trend of firms' carbon information disclosure. In addition, during the pandemic, the impact of various factors on the quality of firms' carbon information disclosure may also be disturbed. And considering that the time for firms to resume normal production and operation after the pandemic is not long enough to obtain observation samples for a long enough sample period, this study takes

A-share listed firms in China from 2015 to 2019 as research sample to explore the inter-provincial differences and influencing factors of firms' carbon information disclosure in China in recent years.

Consistent with previous studies, the following filtering criteria are applied to the initial sample: (1) Remove sample in ST, *ST; (2) Remove firms in financial industry; (3) Remove firms issuing B shares or H shares; (4) Remove firms with debt ratio greater than 1 and samples of firms with missing data; and (5) Apply the Winsorize 5% shrinkage treatment. The final sample includes 4,342 valid observations.

The carbon information is retrieved from the firms' annual reports, environmental reports, corporate social responsibility reports, and sustainability reports. The financial data and other data of firms are from CSMAR database. The regional economic data are from the official website of the National Bureau of Statistics of China. Table 1 shows the sample distribution by provincial-level administrative regions and by industries.

Table 1. Distribution of the Sample by Provincial-Level Administrative Regions and Industries

	N	%
Panel a: by provincial-level administrative regions		
Guangdong	1,544	35.56
Liaoning	168	3.87
Hubei	212	4.88
Shaanxi	135	3.11
Yunnan	79	1.82
Hainan	74	1.70
Tianjin	138	3.18
Chongqing	147	3.39
Beijing	1,089	25.08
Shanghai	756	17.41
Total	4,342	100.00
Panel b: by industries		
Agriculture, forestry, animal husbandry and fishery	29	0.67
Mining industry	122	2.81
Manufacturing industry	2,310	53.20
Industry of electric power, heat, gas and water production and supply	161	3.71
Construction industry	189	4.35
Wholesale and retail industry	223	5.14
Transport, storage and postal service industry	184	4.24
Accommodation and catering industry	26	0.60
Industry of information transmission, software and information technology services	513	11.82
Real estate industry	258	5.94
Leasing and commercial service industry	88	2.03
Scientific research and technical service industry	57	1.31
Water conservancy, environment and public facility management industry	69	1.59
Industry of resident service, repair and other services	1	0.02
Education	11	0.25
Health and social work	6	0.14
Industry of culture, sports and entertainment	74	1.70
Diversified industries	21	0.48
Total	4,342	100.00

3.2 Variables

3.2.1 Dependent Variable

The dependent variable is the quality of firms' carbon information disclosure (CDI). Prior studies mainly adopted two types of methods to measure the quality of firms' carbon information disclosure. One is to measure directly based on the firm's CDP questionnaire score (Hsueh, 2019). The other is to construct the carbon information disclosure index, which uses content analysis to analyze firm's annual reports, environmental reports, corporate social responsibility reports, sustainability reports, and then score the quality of firm's carbon information disclosure (Liu et al., 2017; Kumar & Firoz, 2018). At present, there is no unified international standard for evaluating the quality of firms' carbon information disclosure. And the proportion of A-share listed firms participating in the CDP questionnaire in China is relatively low. Therefore, we adopt the carbon information disclosure index (CDI) used in previous research to measure the quality of firms' carbon information disclosure (Liu et al., 2017). We use content analysis to evaluate the total score of 22 items. A score of one is assigned if a disclosure is related to items in CDI. The items in the CDI are shown in Table 2.

Table 2. Items Included in the Carbon Information Disclosure Index

	ID	Category/item
	CC	**Climate change-related risks, opportunities and actions**
1	CC1	Risks associated with climate change
2	CC2	Description of the actions initiated or planned as a result of identification of risks associated with climate change
3	CC3	Opportunities associated with climate change
4	CC4	Actions initiated or planned as a result of identification of opportunities associated with climate change
	GHG	**GHG emissions accounting**
5	GHG1	Methodology used to calculate GHG emissions
6	GHG2	External verification/assurance status that applies to GHG emissions
7	GHG3	Total GHG emissions
8	GHG4	Breakdown of GHG emissions
9	GHG5	GHG emissions intensity
10	GHG6	Strategies to reduce GHG emissions
11	GHG7	GHG emissions reduction plans
12	GHG8	GHG emissions intensity reduction
	EC	**Energy consumption accounting**
13	EC1	Total energy consumption
14	EC2	Breakdown of energy consumption
15	EC3	Total renewable energy consumption
16	EC4	Breakdown of renewable energy consumption
17	EC5	Strategies to increase renewable energy use
18	EC6	Strategies to reduce energy use
	ACC	**Climate change-related governance and accountability**
19	ACC1	Board committee responsible for climate change risk management
20	ACC2	How the board reviews progress on firms carbon performance
21	ACC3	Incentives for managing GHG emissions and energy use
22	ACC4	Staff development programs to encourage reduction of emissions and energy use

3.2.2 Independent Variables

The independent variables are the influencing factors of the quality of firms' carbon information disclosure. In order to investigate the inter-provincial differences and the influencing factors of the quality of firms' carbon information disclosure in China, this study selects independent variables from the perspectives of external environment, stakeholder, and corporate governance.

- External Environment Variables

Two external environment variables related to firms' carbon information disclosure are used in this study. The first is regional environmental regulation (REG). Under the constraints of government environmental protection policies, firms usually increase their attention to environmental pollution. Therefore, government environmental regulations can promote firms to disclose more environmental information. In recent years, with the increase of environmental governance policies and regulations issued by the Chinese government, the carbon emissions of firms have been more constrained. Considering the cost of violations, more firms are willing to abide by environmental regulations, implement energy conservation and emission reduction plans, and bear the cost of carbon emission management. Moreover, government investment in regional pollution control can promote firms to actively improve production technology, accelerate institutional innovation, and increase investment in pollution control. Therefore, this study uses industrial pollution prevention investment/local GDP to measure the regional environmental regulation (REG) variable.

The second external environment variable related to firms' carbon information disclosure is political connection (PC). Under the institutional background in China, the government plays an important role in the operation and management of firms. For state-owned enterprises with political connections, they have a dual function of stabilizing society and promoting economic development. State-owned enterprises not only obtain economic benefits through legal operations, but also bear important tasks of maintaining social stability, protecting the environment, and building a harmonious society. Compared to non-state-owned enterprises, state-owned enterprises will proactively fulfill more social responsibilities and disclose higher quality environmental information such as carbon information. For non-state-owned enterprises with political connections, they will be more proactive in responding to and implementing government policy and regulations, and proactively disclose carbon information that is of concern to stakeholders such as the government. This study uses the proportion of board members, supervisory board members, and senior management with political backgrounds to measure political connection (PC) variable. In this study, if the directors, supervisors or senior managers of a firm are or used to work in the government, or are or used to be deputies to the National People's Congress or members of the National Committee of the Chinese People's Political Consultative Conference, they are considered to have political backgrounds.

- Stakeholder Variables

Three stakeholder variables related to firms' carbon information disclosure are used in this study. The first is institutional investors (INS). Although the non-governmental organizations (NGOs) and the media have some influence, institutional investors and the government are considered to be the stakeholders who pay the highest attention to climate change and put the greatest pressure on firms (Haque & Islam, 2015). Institutional investors are a powerful and legitimate stakeholder group holding a large number of stocks in the firm. They are an organization eager for firms to actively deal with risks related to climate change. Their investment portfolio is inevitably affected by the operation of firms, and the environmental damage caused by firms will increase the risk cost of institutional investors. In

this study, the shareholding ratio of institutional investors is used to measure the variable of institutional investors.

The second stakeholder variable is creditor pressure (LOANS). Creditors, as one of the primary stakeholders of firms, will have an impact on the carbon information disclosure of firms. When a firm spends a lot of money to manage the environment, the profit of the firm will be reduced, which will affect its solvency, and then bring losses to creditors. In order to ensure that the interests of creditors are not affected, creditors will exert invisible pressure on firms to improve the quality of carbon information disclosure to facilitate creditors' decision-making. In this study, the ratio of bank loans to total liabilities is used to measure the creditor pressure (LOANS) variable.

The third stakeholder variable is the actual controller (STATE). Usually, the government has stronger management over state-owned enterprises, and state-owned enterprises also execute government policies relatively better. For many years, the Chinese government has been encouraging firms to carry out energy conservation, emission reduction, and ecological environment protection activities, and encouraging firms to disclose carbon information and other environmental information. State-owned enterprises with the actual controller being the government have done better in responding to and implementing China's green and low-carbon development policy, and are more inclined to actively disclose high-quality carbon information. This study uses a dummy variable to measure the actual controller (STATE) variable. When the actual controller of a firm is the central or local government, the value is 1, otherwise it is 0.

- Corporate Governance Variables

Four corporate governance variables related to firms' carbon information disclosure are used in this study. The first is the analyst coverage (ANALYST). According to the information and earnings reports disclosed by the firm, analysts predict the firm's risks after considering quantitative and qualitative information. Especially when the macro-economy is highly uncertain, their dependence on qualitative information will increase (Iqbal et al., 2020). Analysts have strong professional ability to deal with financial risk and operational risk information. The high-quality risk information disclosure of the firm is related to the accuracy of analysts' forecasts. The higher the quality of risk information disclosure of the firm, the higher the accuracy of analysts' forecasts. As an important external corporate governance mechanism, analysts' forecasts are of concern to many stakeholders, especially existing investors and potential investors. Therefore, firms will pay attention to the forecast results of analysts, improve the accuracy of analysts' forecasts through high-quality information disclosure to reduce the operational risk of the firm. Through carbon information disclosure, firms can improve operational transparency and reduce environmental governance risks (Zhao et al., 2020). The analyst coverage (ANALYST) variable in this study is measured by the number of analysts' earnings forecasts. The value of this variable is the natural logarithm of 1 plus the number of analysts who make earnings forecasts for the same listed firm in a certain year.

The second corporate governance variable is executive educational background (MAJOR). Executives play a leading role in the decision-making process of firms, but they are not always rational. They will be affected by their own preferences and make decisions that are biased towards their own values. The educational background has an important impact on the formation and development of individual values, so the education background of executives may affect the firm's management decisions to a certain extent. Previous studies have found that the educational background of executives can affect firms' behaviors and outcomes (Finkelstein et al., 2008). Firms led by executives with MBA degrees

are more likely to disclose voluntary environmental information than other firms (Lewis et al., 2014). Therefore, this study will explore the influence of the business or economic management educational background of the executives on the quality of firms' carbon information disclosure. The executive educational background (MAJOR) variable in this study is a dummy variable. When the educational background of the president or CEO is business or economic management, the variable value is 1, otherwise it is 0.

The third corporate governance variable is board gender diversity (FEMALE). The board of directors has the responsibility for strategy and reporting carbon information and it is important that firms structure their board so they have the capacity to manage carbon emissions and other climate change-related risks (Tauringana & Chithambo, 2015). Existing research has found that firms with women on their boards are more likely to address emerging strategic issues related to climate change and greenhouse gas emissions, communicate with stakeholders about this action, and disclose higher quality carbon information (Hollindale et al., 2019). The board gender diversity (FEMALE) variable in this study is measured by the proportion of female directors.

The fourth corporate governance variable is board independence (INDE). A key function of the board of directors is to guide and monitor senior management to ensure that they represent the interests of shareholders and other stakeholders. It is generally believed that the board with a higher proportion of independent directors can more effectively monitor senior management. Empirical evidence shows that the existence of independent directors is positively related to general voluntary disclosure and specific environmental, CSR, and carbon disclosure (Chau & Gray, 2010; de Villiers et al., 2011; Liao et al., 2015). The board independence variable (INDE) in this study is measured by the proportion of independent directors.

3.2.3 Control Variables

Based on the previous research on the influencing factors of firms' carbon information disclosure, this study considers the firm characteristics factors affecting carbon information disclosure, including: firm size (SIZE), environmental committee (ENVCOM), heavily polluting industry (POL), profitability (ROA), leverage (DEB), and firm growth (GROW). Considering the differences in geographical location and economic development among different provincial-level administrative regions in China, this study also considers the factors affecting carbon information disclosure at the provincial level, including: coastal area (AREA), economic level (PGDP), and industrial structure (INSTR). The heavily polluting industry in this study refer to the following 16 industries identified by the Ministry of Environmental Protection of China: thermal power generation, steel, cement, electrolytic aluminium, coal, metallurgy, chemicals, petrochemicals, building material, paper, brewing, pharmaceuticals, fermentation, textile, leather, and mining (He et al., 2021c). In addition, this study controls for industry and year effects. The definition and measurement of each variable is detailed in Table 3.

Table 3. Variable Definitions

Variable	Symbol	Definition
Quality of carbon information disclosure	CDI	Carbon Information Disclosure Index
Regional environmental regulation	REG	Regional investment in industrial pollution control/regional GDP
Political connection	PC	Percentage of board members, supervisory board members, and senior management with political backgrounds
Institutional investors	INS	Institutional investors' shareholding ratio
Creditor pressure	LOANS	The ratio of bank loans to total liabilities
Actual controller	STATE	A dummy variable that equals to 1 if the firm is state-owned and 0 otherwise
Analyst coverage	ANALYST	The natural logarithm of 1 plus the number of analysts who made earnings forecasts for a firm during the year
Executive educational background	MAJOR	A dummy variable that equals to 1 if the educational background of president or CEO is business or economic management and 0 otherwise
Board gender diversity	FEMALE	The percentage of female directors on the board
Board independence	INDE	The percentage of independent directors on the board
Firm size	SIZE	The natural logarithm of total assets
Environmental committee	ENVCOM	A dummy variable that equals to 1 if the firm has an environment committee and 0 otherwise
Heavily polluting industry	POL	A dummy variable that equals to 1 if the firm belongs to a heavily polluting industry and 0 otherwise
Profitability	ROA	The ratio of net profit to total assets
Leverage	DEB	The ratio of total debt divided by total assets
Firm growth	GROW	Revenue growth rate
Coastal area	AREA	A dummy variable that equals to 1 if the region where the firm is located is a coastal area and 0 otherwise
Economic level	PGDP	The natural logarithm of GDP per capita of the region where the firm is located
Industrial structure	INSTR	GDP of the tertiary industry/GDP of the secondary industry of the region where the firm is located
Industry	INDUSTRY	Industry dummies
Year	YEAR	Year dummies

3.3 Research Model

In order to test the influencing factors that affect the quality of firms' carbon information disclosure, this study uses the following ordinary least square (OLS) regression model:

$$CDI = \alpha + \beta_1 REG + \beta_2 PC + \beta_3 INS + \beta_4 LOANS + \beta_5 STATE + \beta_6 ANALYST + \beta_7 MAJOR + \beta_8 FEMALE + \beta_9 INDE + \beta_{10} SIZE + \beta_{11} ENVCOM + \beta_{12} POL + \beta_{13} ROA + \beta_{14} DEB + \beta_{15} GROW + \beta_{16} AREA + \beta_{17} PGDP + \beta_{18} INSTR + \sum \beta_i INDUSTRY_i + \sum \beta_j YEAR_j + \varepsilon$$

where the dependent variable CDI denotes the quality of carbon information disclosure, α is a constant term, the independent variable REG denotes regional environmental regulation, PC denotes political connection, INS denotes institutional investors, LOANS denotes creditor pressure, STATE denotes actual controller, ANALYST denotes analyst coverage, MAJOR denotes executive educational background, FEMALE denotes board gender diversity, INDE denotes board independence, SIZE denotes firm size, ENVCOM denotes environmental committee, POL denotes heavily polluting industry, ROA denotes profitability, DEB denotes leverage, GROW denotes firm growth, AREA denotes coastal area, PGDP denotes economic level, INSTR denotes industrial structure, ε represents the random perturbation term.

4. Empirical Results

4.1 Inter-Provincial Differences in the Quality of Carbon Information Disclosure

4.1.1 Descriptive Analysis

The descriptive statistics of carbon information disclosure scores from 2015 to 2019 are presented in Table 4. The key observations are as follows: in 2015, 329 of the 832 firms (39.54%) disclose carbon information in their annual reports, environmental reports, CSR reports, and sustainability reports. The results are improved in 2017 when 389 of 935 firms (41.60%) disclose carbon information. In 2018, the proportion of firms that disclose carbon information further increases to 354 of the 832 firms (42.55%). The proportion of firms that disclose carbon information in 2017 and later is higher than that before 2017. And the average score of carbon information disclosure has increased from 0.97 in 2015 to 1.14 in 2018. The average score of carbon information disclosure in 2017 and later is also higher than that before 2017. The data confirms that the proportion of firms disclosing carbon information and the quality of disclosure improved over the research period.

Table 4. Descriptive Statistics of Carbon Information Disclosure Scores from 2015 to 2019

Year	Number of samples	Number of firms with CDI >0	Ratios of firms with CDI > 0	Means	SD	Min	Max
2015	832	329	39.54%	0.97	1.63	0	15
2016	926	360	38.88%	1.01	1.75	0	13
2017	935	389	41.60%	1.09	1.84	0	15
2018	832	354	42.55%	1.14	1.94	0	13
2019	817	337	41.25%	1.04	1.67	0	10

Table 5 presents the percentage distribution of carbon information disclosure scores for each item. The index of carbon information disclosure quality in this study includes four categories, which are climate change-related risks, opportunities and actions (CC), GHG emissions accounting (GHG), Energy consumption accounting (EC), and Climate change-related governance and accountability (ACC). Each category includes several scoring items, with a total of 22 items in the four dimensions, each accounting for 4.55% of the index's full score. This study divided the scores of each item in the carbon information disclosure quality index of all sample firms by the total score of all items to obtain the proportion of scores for each item. It can be found from table 5 that only five items (GHG6, EC1, EC6, ACC3, and ACC4) have scores accounting for more than 4.55%. And the score proportion of the five items such as CC4, GHG1, GHG2, GHG8, and ACC1 is less than 0.5%. The proportion of the scores of each item shows that the sample firms can actively respond to the government's energy conservation

and emission reduction policies in strategy formulation, and encourage employees to practice energy conservation and emission reduction in their daily work. However, in the implementation of the strategy, there is a lack of action plan, accounting method of carbon emissions and corresponding corporate governance mechanism, and the quantitative carbon emission information disclosure is insufficient.

Table 5. Percentage Distribution of Carbon Information Disclosure Scores for Each Item

Categories	Items	%
CC	CC1	3.75
	CC2	1.95
	CC3	0.50
	CC4	0.20
GHG	GHG1	0.17
	GHG2	0.20
	GHG3	4.47
	GHG4	1.82
	GHG5	0.53
	GHG6	15.53
	GHG7	0.55
	GHG8	0.06
EC	EC1	6.89
	EC2	3.11
	EC3	2.08
	EC4	1.47
	EC5	4.19
	EC6	19.17
ACC	ACC1	0.42
	ACC2	0.66
	ACC3	18.79
	ACC4	13.49

Table 6 shows the level of average carbon information disclosure scores for eighteen industries from 2015 to 2019. The eighteen industries under the Guidelines for Industry Classification of Listed Companies issued by the China Securities Regulatory Commission are: agriculture, forestry, animal husbandry and fishery, mining industry, manufacturing industry, industry of electric power, heat, gas and water production and supply, construction industry, wholesale and retail industry, transport, storage and postal service industry, accommodation and catering industry, industry of information transmission, software and information technology services, real estate industry, leasing and commercial service industry, scientific research and technical service industry, water conservancy, environment and public facility management industry, industry of resident service, repair and other services, education, health and social work, industry of culture, sports and entertainment, and diversified industries.

From Table 6, it can be found that the disclosure quality of firms in all industries is generally not high, especially firms in the industries of resident service, repair and other services, education, and health and social work rarely disclose carbon information. From 2015 to 2018, the three industries with the highest carbon information disclosure scores are the transport, storage and postal service industry, the

industry of electric power, heat, gas and water production and supply, and the mining industry. In 2019, the top three industries with the highest carbon information disclosure scores are the health and social work, the transport, storage and postal service industry, and the construction industry. Except for the health and social work industry in 2019, the top three industries with the highest carbon information disclosure scores in each year are all carbon intensive industries. From 2015 to 2018, listed firms in the health and social work industry in China rarely disclosed carbon information. Due to the outbreak and spread of the pandemic in early 2020, the health and social work industry has received a sharp increase in attention. Therefore, when listed firms in the health and social work industry disclosed their 2019 information in 2020, they improved the disclosure quality of their environmental and social responsibility information such as carbon information, becoming the industry with the highest disclosure score in 2019. From Table 6, it can also be observed that, except for a few industries that experienced a decrease in disclosure scores in 2019 compared to 2018 due to the impact of the pandemic, the disclosure quality of most industries is gradually improving. Only the disclosure scores of the agriculture, forestry, animal husbandry and fishery industry are showing a downward trend.

Table 6. Comparison of Carbon Information Disclosure Scores among Industries from 2015 to 2019

Industries	2015	2016	2017	2018	2019
Agriculture, forestry, animal husbandry and fishery	1.22	1.14	0.83	0.75	0.33
Mining industry	2.08	2.39	2.17	2.35	1.32
Manufacturing industry	0.87	0.91	1.04	1.11	0.97
Industry of electric power, heat, gas and water production and supply	1.83	2.38	2.53	2.41	1.68
Construction industry	1.17	1.07	1.30	1.41	1.69
Wholesale and retail industry	1.09	1.20	1.16	1.22	0.85
Transport, storage and postal service industry	2.08	2.14	2.45	2.61	2.52
Accommodation and catering industry	1.14	1.67	1.20	1.25	1.50
Industry of information transmission, software and information technology services	0.49	0.53	0.48	0.55	0.65
Real estate industry	0.90	0.78	1.16	1.10	1.28
Leasing and commercial service industry	0.36	0.42	0.29	0.28	0.50
Scientific research and technical service industry	0.60	0.50	0.11	0.21	0.21
Water conservancy, environment and public facility management industry	0.77	0.75	0.83	0.73	0.94
Industry of resident service, repair and other services				0.00	
Education	0.00	0.00	0.00	0.00	0.00
Health and social work		0.00	0.00	0.50	3.00
Industry of culture, sports and entertainment	0.56	0.57	0.47	0.59	0.59
Diversified industries	1.14	0.67	0.80	2.00	0.00

4.1.2 Inter-Provincial Differences Analysis

The level of average carbon information disclosure scores for ten provincial-level administrative regions in China from 2015 to 2019 is shown in Table 7. From Table 7, it can be observed that the carbon information disclosure scores of most provincial-level administrative regions are showing an increasing trend, indicating that the carbon information disclosure awareness of listed firms in China is continuously improving. But in 2019, the disclosure scores of most provincial-level administrative regions have decreased, possibly due to the impact of the outbreak of the pandemic in early 2020. The pandemic has brought many obstacles to the collection, processing, and auditing of carbon information, and many listed firms have postponed the disclosure of their 2019 annual reports. In addition, during the pandemic, firms tend to focus more on disclosing information related to the pandemic when preparing environmental and social responsibility reports, which to some extent affects the disclosure of carbon information. It can also be found from Table 7 that the quality of carbon information disclosure in ten provincial-level administrative regions is generally not high. Among them, the quality of carbon information disclosure in Hainan, Tianjin, Beijing, and Shanghai is relatively good, with most years exceeding the average level. The quality of carbon information disclosure in Liaoning has shown an increasing trend, exceeding the average level since 2018. The quality of carbon information disclosure in Guangdong and Hubei has been lower than the average level in each year.

Table 7. Comparison of Carbon Information Disclosure Scores among Ten Provincial-Level Administrative Regions from 2015 to 2019

Provincial-level administrative regions	2015	2016	2017	2018	2019
Guangdong	0.71	0.69	0.83	0.90	0.90
Liaoning	0.75	0.88	1.08	1.26	1.12
Hubei	0.76	0.76	0.76	0.61	0.46
Shaanxi	0.70	0.94	0.90	1.24	1.00
Yunnan	1.00	1.12	0.94	0.81	1.21
Hainan	1.24	1.35	1.27	1.27	0.43
Tianjin	1.17	1.68	1.55	1.46	1.00
Chongqing	0.45	0.43	0.84	0.95	1.08
Beijing	1.18	1.17	1.22	1.26	1.19
Shanghai	1.38	1.50	1.55	1.53	1.30
Average	0.93	1.05	1.09	1.13	0.97

Table 8 presents the average score of carbon information for each category disclosed by each provincial-level administrative region between 2015 and 2019. We can find that, on average, the disclosure quality of EC and ACC in each provincial-level administrative region is relatively high, and the disclosure quality of CC is generally low, indicating that firms in China generally attach importance to the calculation and statistics of energy consumption, and also attach importance to climate change issues in corporate governance. However, they are relatively weak in GHG emission calculation, and do not attach enough importance to the identification and response to climate change related risks and opportunities. In the formulation of firm strategies, climate change is generally not considered as an important factor in external and internal environmental analysis. Furthermore, Table 8 shows that the disclosure quality of GHG, EC, and ACC categories by firms in Shanghai, Tianjin, and Beijing is

higher than the average level. The disclosure quality of CC, GHG, and ACC categories by firms in Hainan is higher than the average level, and the disclosure quality of CC category is much higher than in other provincial-level administrative regions.

Table 8. Comparison of Carbon Information Disclosure Scores for Each Category among Ten Provincial-Level Administrative Regions

Provincial-level administrative regions	CC	GHG	EC	ACC
Guangdong	0.06	0.20	0.26	0.28
Liaoning	0.09	0.24	0.34	0.32
Hubei	0.04	0.16	0.22	0.25
Shaanxi	0.06	0.10	0.43	0.36
Yunnan	0.03	0.19	0.28	0.52
Hainan	0.28	0.26	0.23	0.43
Tianjin	0.04	0.33	0.57	0.45
Chongqing	0.01	0.15	0.29	0.27
Beijing	0.09	0.28	0.47	0.37
Shanghai	0.06	0.33	0.60	0.47
Average	0.08	0.22	0.37	0.37

The average score of carbon information disclosed by each industry among ten provincial-level administrative regions in China between 2015 and 2019 is shown in Table 9. From Table 9, it can be observed that in most provincial-level administrative regions, the top three industries with the highest carbon information disclosure scores include two industries: industry of electric power, heat, gas and water production and supply, and transport, storage and postal service industry; The mining industry is also one of the top three industries with the highest carbon information disclosure scores in Shaanxi, Yunnan, Tianjin, and Beijing; Three provincial-level administrative regions with sample firms in the industry of resident service, repair and other services, and in the education industry have not disclosed carbon information. This indicates that high carbon industries in most provincial-level administrative regions usually have relatively high carbon information disclosure quality, while industries with relatively low carbon emissions have relatively low carbon information disclosure quality. From Table 9, it can also be observed that the four provincial-level administrative regions of Beijing, Shanghai, Hainan, and Liaoning have relatively high disclosure scores in several industries. Beijing ranks in the top three disclosure scores in ten industries, Shanghai ranks in the top three disclosure scores in seven industries, and Hainan and Liaoning rank in the top three disclosure scores in five industries. Moreover, Beijing has the highest disclosure scores in five industries: construction industry, transport, storage and postal service industry, real estate industry, water conservancy, environment and public facility management industry, and industry of culture, sports and entertainment; Hainan has the highest disclosure scores in four industries: agriculture, forestry, animal husbandry and fishery, wholesale and retail industry, accommodation and catering industry, and industry of information transmission, software and information technology services.

Table 9. Comparison of Carbon Information Disclosure Scores by Industry among Ten Provincial-Level Administrative Regions

Industry	All samples	Guangdong	Liaoning	Hubei	Shaanxi	Yunnan	Hainan	Tianjin	Chongqing	Beijing	Shanghai
Agriculture, forestry, animal husbandry and fishery	0.97	0.43	1.60			0.00	1.83			1.20	0.00
Mining industry	2.06	0.00	0.00		1.29	4.50	0.62	3.00	0.00	2.90	0.89
Manufacturing industry	0.98	0.82	0.55	0.76	0.82	1.24	0.75	0.68	0.79	1.02	1.63
Industry of electric power, heat, gas and water production and supply	2.17	2.15	4.10	0.33	0.40	2.50		2.00	1.04	2.80	3.83
Construction industry	1.31	0.44		0.50	0.00		0.00		0.00	2.11	1.45
Wholesale and retail industry	1.11	0.34	0.85	1.15	2.83	0.00	3.00	1.38	0.29	1.24	1.93
Transport, storage and postal service industry	2.34	1.92	2.45	0.00			2.64	4.00	0.20	5.64	2.03
Accommodation and catering industry	1.35	1.00			0.50		2.00			1.40	2.00
Industry of information transmission, software and information technology services	0.54	0.32	1.24	0.00	0.75	0.00	2.00	1.00	1.14	0.47	0.80
Real estate industry	1.02	0.98	0.00	0.00		0.57	0.78	0.50	0.29	1.44	1.15
Leasing and commercial service industry	0.36	0.38			1.60					0.25	0.00
Scientific research and technical service industry	0.32	0.31	0.00					1.67		0.20	0.25
Water conservancy,	0.81	1.18	0.00	0.50	0.57	0.00		0.00	0.80	1.67	0.00

environment and public facility management industry										
Industry of resident service, repair and other services	0.00								0.00	
Education	0.00		0.00						0.00	0.00
Health and social work	1.17	1.25			1.00					
Industry of culture, sports and entertainment	0.56	0.25	0.83	0.08		0.00	0.00	0.00	0.97	0.36
Diversified industries	0.86	0.29	1.00	3.00		1.00			0.00	1.67

4.2 Influencing Factors of the Quality of Carbon Information Disclosure

4.2.1 Descriptive Statistics of Variables

Table 10 shows the descriptive statistics of the variables. We can find that the average CDI is 1.05, with minimum and maximum values of 0 and 15, respectively. However, the index has a maximum score of 22 points, indicating that the overall quality of carbon information disclosure by firms in China is relatively low. The average value of POL is 0.21, indicating that firms in heavily polluting industries account for 21% of the sample. The average ENVCOM value is 0.03, indicating that only about 3% of the sample firms have established environmental committees, which is a relatively small proportion. The average values of STATE and AREA are 0.36 and 0.87, respectively, indicating that the majority of the sample firms are non-state-owned and located in coastal area. The average value of PGDP is 11.43, with minimum and maximum values of 10.27 and 12.01 respectively, indicating an imbalance in economic development in the regions where the sample firms are located.

Table 10. Descriptive Statistics of Variables

Variable	N	Mean	SD	Min	Max
CDI	4,342	1.05	1.77	0	15
REG	4,342	0.00053	0.00041	0.00002	0.00184
PC	4,342	0.04	0.07	0	0.59
INS	4,342	0.07	0.07	0	0.63
LOANS	4,342	0.25	0.21	0	0.92
STATE	4,342	0.36	0.48	0	1
ANALYST	4,342	2.03	0.89	0.69	4.33
MAJOR	4,342	0.55	0.50	0	1
FEMALE	4,342	0.14	0.13	0	0.71
INDE	4,342	0.38	0.06	0	0.80
SIZE	4,342	22.70	1.49	18.47	28.64

ENVCOM	4,342	0.03	0.17	0	1
POL	4,342	0.21	0.41	0	1
ROA	4,342	0.04	0.07	-1.07	0.38
DEB	4,342	0.436	0.198	0.017	0.998
GROW	4,342	1.02	30.13	-0.92	1,881
AREA	4,342	0.87	0.34	0	1
PGDP	4,342	11.43	0.36	10.27	12.01
INSTR	4,342	2.41	1.52	0.88	5.23

4.2.2 Correlation Analysis

Table 11 presents a correlation matrix between the main variables. We can observe a significant negative correlation between FEMALE and CDI. ROA and GROW are not significantly correlated with CDI. All other variables are significantly positively correlated with CDI. We can also find that the correlation coefficient between ANALYST and INS is 0.397, the correlation coefficient between DEB and LOANS is 0.390, and the correlation coefficient between DEB and SIZE is 0.584, all of which are significant at the 1% level. The correlation coefficients between other explanatory variables are all less than 0.3. Table 11 shows that the values of the variance inflation factors (VIF) are less than 3, and the values of tolerance are greater than 0.3. The above correlations analysis results indicate that multicollinearity does not seem to affect the predicted values of our models.

Table 11. Variance Inflation Factor Test for Variables

Variable	VIF	Tolerance
REG	1.08	0.9232
PC	1.03	0.9667
INS	1.21	0.8243
LOANS	1.26	0.7913
STATE	1.39	0.7217
ANALYST	1.44	0.6929
MAJOR	1.03	0.9667
FEMALE	1.05	0.9567
INDE	1.02	0.9806
SIZE	2.16	0.4619
ENVCOM	1.02	0.9806
POL	1.11	0.9041
ROA	1.21	0.8243
DEB	1.93	0.5174
GROW	1.01	0.9930
AREA	1.52	0.6579
PGDP	2.79	0.3588
INSTR	2.24	0.4473

Table 12. Correlation Matrix of the Main Variables

	CDI	REG	PC	INS	LOANS	STATE	ANALYST	MAJOR	FEMALE	INDE	SIZE	ENVCOM	POL	ROA	DEB	GROW	AREA	PGDP	ISTR
CDI	1.000																		
REG	0.057**	1.000																	
PC	0.068**	-0.028*	1.000																
INS	0.052**	-0.028*	0.010	1.000															
LOANS	0.063**	0.011	0.053**	-0.007	1.000														
STATE	0.296**	0.100**	0.018	-0.009	0.046**	1.000													
ANALYST	0.184**	-0.057**	0.038*	0.397**	-0.079***	-0.001	1.000												
MAJOR	0.037*	-0.005	0.088**	0.019	0.057**	0.068**	0.026*	1.000											
FEMALE	-0.125***	-0.042**	0.016	-0.019	0.020	-0.134***	-0.096**	-0.005	1.000										
INDE	0.041**	0.001	0.035*	-0.003	-0.002	-0.026*	0.044**	-0.029*	-0.007	1.000									
SIZE	0.496**	-0.022	0.124**	0.178**	0.188**	0.451**	0.304**	0.091**	-0.162**	0.070**	1.000								
ENVCOM	0.133**	-0.002	0.024*	0.018	0.004	0.062**	0.058**	0.011	0.008	-0.040***	0.067**	1.000							
POL	0.119**	0.015	0.012	0.010	0.136**	0.102**	0.023	-0.033**	0.031**	0.006	0.078**	0.077**	1.000						
ROA	-0.003	0.005	-0.012	0.096**	-0.198***	-0.044***	0.268**	-0.008	0.003	-0.014	-0.063***	0.033**	0.074**	1.000					
DEB	0.220**	0.009	0.097**	0.082**	0.390**	0.283**	0.057**	0.078**	-0.072**	0.019	0.584**	0.019	-0.063***	-0.272**	1.000				
GROW	-0.014	0.009	0.010	-0.016	0.004	-0.014	-0.002	-0.014	-0.007	-0.015	0.049**	-0.004	-0.007	-0.002	0.045**	1.000			
AREA	0.056**	-0.093**	0.024	-0.020	-0.045***	-0.128***	0.002	-0.017	0.029*	0.035*	-0.024*	0.008	-0.127***	0.011	-0.071***	0.005	1.000		
PGDP	0.106**	-0.049**	-0.023	-0.037*	-0.090***	-0.014	0.073**	-0.041***	-0.009	0.019	0.096**	0.057**	-0.092***	0.026*	-0.034**	0.000	0.553***	1.000	
INSTR	0.088**	-0.180**	-0.052***	0.028*	-0.073***	0.076**	0.083**	-0.068***	-0.008	0.003	0.120**	0.049**	-0.011	-0.022	-0.024	-0.004	0.321***	0.709***	1.000

Note. ***p < 0.01, **p < 0.05, *p < 0.1.

4.2.3 Regression Analysis

Column (1) in Table 13 presents the whole sample regression results of the influencing factors of the quality of carbon information disclosure. The regression result of Column (1) indicates that regional environmental regulation in external environmental factors, actual controller in stakeholder factors, analyst coverage in corporate governance factors, firm size, environmental committee, and heavily polluting industry in firm characteristics factors, and coastal area and economic level in provincial level factors all have a significant positive impact on the quality of firms' carbon information disclosure. Institutional investors and creditor pressure in stakeholder factors, board gender diversity in corporate governance factors, leverage and firm growth in firm characteristics factors have a significant negative impact on the quality of firms' carbon information disclosure.

Table 13. Regression Results of Influencing Factors of the Quality of Carbon Information Disclosure

Variables	Whole sample (1)	East coastal area of China (2)	Central and western China (3)
REG	0.099***	0.100***	0.086
	(3.51)	(3.01)	(0.89)
PC	0.466	0.681*	-1.168
	(1.32)	(1.79)	(-1.21)
INS	-0.852**	-1.046**	0.420
	(-2.27)	(-2.58)	(0.43)
LOANS	-0.256**	-0.378***	0.743**
	(-2.04)	(-2.76)	(2.51)
STATE	0.239***	0.281***	0.188
	(4.20)	(4.38)	(1.60)
ANALYST	0.074**	0.073**	0.064
	(2.35)	(2.12)	(0.87)
MAJOR	-0.012	-0.015	0.108
	(-0.26)	(-0.29)	(0.99)
FEMALE	-0.438**	-0.433**	-0.879**
	(-2.45)	(-2.23)	(-2.05)
INDE	0.421	0.833**	-2.496***
	(1.13)	(2.06)	(2.69)
SIZE	0.585***	0.599***	0.370***
	(24.77)	(23.07)	(6.69)
ENVCOM	0.827***	0.807***	0.918***
	(6.14)	(5.52)	(2.84)
POL	0.197***	0.116	0.412***
	(2.96)	(1.54)	(2.97)
ROA	-0.198	-0.161	-0.169
	(-0.55)	(-0.42)	(-0.15)
DEB	-0.329**	-0.213	-1.197***
	(-1.97)	(-1.17)	(-3.05)
GROW	-0.002**	-0.002**	-0.005
	(-2.48)	(-2.45)	(-0.47)
AREA	0.323***		

	(3.67)		
PGDP	0.320**	0.310**	0.615
	(2.47)	(2.02)	(0.26)
INSTR	-0.020	-0.020	0.730
	(-0.80)	(-0.69)	(-0.19)
INDUSTRY	control	control	control
YEAR	control	control	control
Constant	-15.641***	-15.643***	-8.761
	(-10.76)	(-8.86)	(-1.16)
Observations	4342	3769	573
Adjusted R^2	0.3063	0.3273	0.1687
Prob > F	0.0000	0.0000	0.0000

Note. ***p < 0.01, **p < 0.05, *p < 0.1. The t-statistics are in parentheses.

The above results indicate that strengthening regional environmental regulation can promote the improvement of the quality of carbon information disclosure by firms. The survival and development of firms need to comply with the regulations and policies formulated by the government. The government's emphasis on environmental protection and governance can promote firms to disclose more carbon information to obtain or maintain the legitimacy of their operations. In China, green and sustainable development has become the core of the national strategy. Through carbon information disclosure, state-owned enterprises can demonstrate their commitment to sustainable operations to align with the country's green development strategy. Analyst coverage, as an important external governance mechanism, can encourage firms to pay more attention to carbon information disclosure. Analysts' research reports have a significant impact on investors, as their opinions and recommendations often guide the flow of their funds. By monitoring a firm's carbon information disclosure, analysts can help investors better evaluate the firm's environmental risks and investment value. In order to gain recognition and recommendations from analysts, firms will actively disclose carbon information and showcase their efforts and achievements in environmental protection and sustainable development.

Due to some institutional investors' emphasis on short-term returns, they may overlook the long-term environmental and social responsibilities of the firms, resulting in a negative correlation between institutional investors' shareholding ratio and the quality of carbon information disclosure. In addition, when firms face significant financial pressure due to high debt, they may allocate limited resources more towards debt repayment and daily operations, without sufficient resources and motivation to improve the quality of carbon information disclosure. The proportion of female directors is significantly negatively correlated with carbon information disclosure, which may indicate that only when there are a sufficient number of female directors, the inhibitory effect of female directors on carbon information disclosure will weaken and have a positive impact (Hollindale et al., 2019; De Masi et al., 2021). In addition, the positive impact of female directors on the quality of carbon information disclosure may also depend on factors such as their power and educational background (He et al., 2021c).

4.2.4 Additional Analysis

Considering that the regression results of Column (1) in Table 13 show a significant positive impact of coastal area on the quality of firms' carbon information disclosure, we conducted grouped regression on this factor. We divided the samples from Hubei, Shaanxi, Yunnan, and Chongqing into the central and western China group, and the samples from other provincial-level administrative regions into the eastern coastal area of China group. The regression results are shown in Column (2) and Column (3) in Table 13. From Column (2), it can be observed that, except for political connections, board independence, heavily polluting industries, and leverage, the regression results of the east coastal area of China sample are consistent with the full sample regression results. From Column (3), it can be observed that, except for board gender diversity, firm size, environmental committee, and profitability, the regression results of the samples from the central and western China are inconsistent with those from the east coastal area of China. The above regression results indicate that there are significant differences in the influencing factors of carbon information disclosure quality among firms in different regions in China.

Due to the relatively lagging economic development in the central and western China, firms in this area face more pressure and challenges in their operations, and there are relatively more heavily polluting firms. This leads to different impacts of the same factor on the quality of carbon information disclosure for firms in the east coastal area of China and in the central and western China. For example, due to the relatively weak environmental regulations in the central and western China, firms in these regions may not attach enough importance to environmental regulations. Therefore, regional environmental regulation may not have a significant impact on the carbon information disclosure of firms in the central and western China. Even state-owned enterprises may not have relatively high carbon information disclosure quality. Compared to the central and western China, there are fewer heavily polluting firms in the east coastal area of China. In the east coastal area of China where heavily polluting industry factor has less impact, political connection and board independence may help firms improve the quality of carbon information disclosure. However, in the central and western China where heavily polluting industry factor has a great impact, the promotion effect of political connection and board independence on firms' carbon information disclosure is limited and may even have a negative impact.

The capital markets in the east coastal area of China may be relatively mature, and the competition among institutional investors is fierce. Therefore, institutional investors may focus more on short-term financial performance rather than long-term sustainable development. This short-termism may lead to a decline in the quality of carbon information disclosure by firms. In addition, firms in the east coastal area of China may face greater market competition pressure. When they face significant financial pressure due to high debt, they will not have sufficient resources and motivation to improve the quality of carbon information disclosure. Therefore, in the east coastal area of China where equity financing channels are relatively abundant and costs are relatively low, creditor pressure has no significant positive impact on the quality of firms' carbon information disclosure, while analyst coverage has a significant positive impact on the quality of firms' carbon information disclosure. However, in the central and western China where equity financing channels are relatively scarce and costs are relatively high, firms still mainly rely on debt financing channels such as bank loans. In order to reduce financing costs, firms will improve the quality of carbon information disclosure due to pressure from creditors,

while analyst coverage may not have a significant impact on the quality of firms' carbon information disclosure.

4.2.5 Robustness Checks

As the variable indicators selected in the model construction will affect the results of the empirical evidence, in order to further verify the reliability of the results, we use alternative measures for variables to conduct robustness tests. We replace REG with the annual operating cost of industrial waste gas treatment facilities. We replace PC with a dummy variable indicating the presence of board members, supervisory board members, and senior management with political backgrounds. We replace FEMALE and INDE with the number of female directors and independent directors, respectively. And we replace POL with a dummy variable that indicate whether a firm belongs to one of the highest emitting industries (Peng et al., 2015). Table 14 presents the regression results of the robustness tests, which are similar to the previous regression results. In column (3), the variable INDE has a positive effect on the quality of firms' carbon information disclosure, with significance at the 95% confidence level. This may indicate that in central and western China, the promotion effect of independent directors on firms' carbon information disclosure requires a larger number of independent directors.

Table 14. Regression Results of Robustness Tests

Variables	Whole sample (1)	East coastal area of China (2)	Central and western China (3)
REG	0.097***	0.089***	0.100
	(3.06)	(2.62)	(1.27)
PC	0.010	-0.002	0.180
	(0.21)	(-0.05)	(1.63)
INS	-0.826**	-1.065***	0.421
	(-2.20)	(-2.62)	(1.46)
LOANS	-0.185	-0.336**	0.896***
	(-1.48)	(-2.46)	(3.11)
STATE	0.225***	0.256***	0.128
	(3.95)	(3.98)	(1.07)
ANALYST	0.073**	0.072**	-0.011
	(2.31)	(2.09)	(-0.15)
MAJOR	-0.013	-0.018	0.053
	(-0.29)	(-0.36)	(0.49)
FEMALE	-0.064***	-0.070***	-0.107**
	(-2.99)	(-3.00)	(-2.08)
INDE	0.148***	0.150***	0.146**
	(3.84)	(3.33)	(2.12)
SIZE	0.575***	0.593***	0.313***
	(23.90)	(22.41)	(5.52)
ENVCOM	0.881***	0.841***	1.000***
	(6.55)	(5.76)	(3.06)
POL	0.045	0.045	0.201
	(0.74)	(0.67)	(1.45)
ROA	-0.102	-0.111	0.881
	(-0.28)	(-0.29)	(0.79)
DEB	-0.397**	-0.259	-0.992**

	(-2.39)	(-1.43)	(-2.55)
GROW	-0.002***	-0.002***	-0.008
	(-2.61)	(-2.62)	(-0.82)
AREA	0.218**		
	(2.53)		
PGDP	0.557***	0.601***	-0.145
	(4.60)	(4.47)	(-0.29)
INSTR	-0.019	-0.033	-0.329
	(-0.74)	(-1.21)	(-0.64)
INDUSTRY	control	control	control
YEAR	control	control	control
Constant	-18.242***	-18.820***	-5.677
	(-13.21)	(-11.98)	(-0.69)
Observations	4342	3769	573
Adjusted R^2	0.3062	0.3273	0.1583
Prob > F	0.0000	0.0000	0.0000

Note. ***p < 0.01, **p < 0.05, *p < 0.1. The t-statistics are in parentheses.

5. Conclusions and Policy Implications

5.1 Conclusions

The objective of this study is to explore the differences in the quality of carbon information disclosure among firms in different provincial-level administrative regions of China and their influencing factors. This study takes the A-share listed firms of ten low-carbon pilot provincial-level administrative regions in China from 2015 to 2019 as samples, analyzes the differences in the quality of carbon information disclosure by firms in different provincial-level administrative regions, and empirically analyzes the influencing factors of firms' carbon information disclosure quality from the three perspectives of external environment, stakeholders, and corporate governance. The study shows that:

(1) In China, the proportion of firms disclosing carbon information is increasing year by year, and the quality of carbon information disclosed by listed firms is showing an increasing trend, indicating that firms in China are paying more attention to the national carbon information disclosure policy and their awareness of environmental information disclosure is gradually improving. Moreover, there are differences in the quality of carbon information disclosure among listed firms in different regions of China. The carbon information disclosure quality of listed firms in the eastern coastal area of China is generally higher than that of listed firms in the central and western China. However, the overall quality of carbon information disclosure by firms in China is still relatively low, and there is great potential for improvement in the future.

(2) The content of carbon information disclosure by listed firms in China is not comprehensive, with relatively more disclosure in energy consumption accounting and climate change-related governance and accountability, less disclosure in GHG emissions accounting, and very little disclosure in climate change-related risks, opportunities and actions.

(3) There are industry differences in the quality of carbon information disclosure among listed firms in China. The carbon information disclosure quality of listed firms in industries such as transport, storage and postal service industry, industry of electric power, heat, gas and water production and supply, and mining industry is relatively high, while the carbon information disclosure quality of listed firms in

industries such as industry of resident service, repair and other services, education, scientific research and technical service industry, leasing and commercial service industry, industry of information transmission, software and information technology services, industry of culture, sports and entertainment is relatively low. In addition, due to differences in industrial distribution and regional environmental regulations in different regions of China, the quality of carbon information disclosure of listed firms in the same industry in different regions also varies. For example, in industries such as agriculture, forestry, animal husbandry and fishery, wholesale and retail industry, accommodation and catering industry, industry of information transmission, software and information technology services, listed firms in Hainan have the highest quality of carbon information disclosure. However, in industries such as construction industry, transport, storage and postal service industry, real estate industry, water conservancy, environment and public facility management industry, industry of culture, sports and entertainment, listed firms in Beijing have the highest quality of carbon information disclosure.

(4) There are regional differences in the influencing factors of carbon information disclosure quality among listed firms in China. The research results on the influence of board gender diversity, firm size, and environmental committee on the quality of carbon information disclosure of listed firms in different regions are consistent. For listed firms in the eastern coastal area of China, regional environmental regulation, actual controller, analyst coverage, board independence, and economic level have a positive impact on carbon information disclosure, while institutional investors, creditor pressure, and firm growth have a negative impact on carbon information disclosure. However, most of the above factors have no significant impact on the quality of carbon information disclosure of listed firms in the central and western China.

5.2 Policy Implications

Based on our research results, we have concluded four policy recommendations.

Firstly, the government and regulators should promote mandatory disclosure and standardized disclosure of carbon information for all listed firms through policy-making. The Chinese capital market has not yet required all listed firms to disclose carbon information, so the overall quality of carbon information disclosure by listed firms is relatively low, and there is less disclosure of climate change-related risks, opportunities, and actions, as well as GHG emissions accounting. Due to the uneven regional economic development and differences in industrial structure distribution, the quality of carbon information disclosure by listed firms in different regions of China is also different. The quality of carbon information disclosure by listed firms in central and western China is relatively low. The government and regulators should develop a unified carbon information disclosure framework and mandatory carbon information disclosure requirements that are in line with international standards as soon as possible, in order to narrow the gap in carbon information disclosure quality between listed firms in the eastern coastal area of China and in the central and western China, and promote comprehensive and high-quality disclosure of carbon information by listed firms.

Secondly, the government or industry associations should develop industry carbon information disclosure guidelines or standards based on the characteristics of products or services in different industries. Due to differences in carbon emissions, composition of direct and indirect emissions, and carbon management across different industries, the actual quality of carbon information disclosure may vary even if disclosed under the same unified framework. The government or industry associations should develop carbon information disclosure guidelines or standards that are in line with the industry's carbon emission characteristics based on the characteristics of products or services in different

industries, on the basis of the unified carbon information disclosure framework mentioned above, in order to promote high-quality disclosure of carbon information by listed firms in different industries, promote green development of firms and green transformation of industries. For example, the direct carbon emissions of the industry of resident service, repair and other services, and education industry are relatively low, and the quality of carbon information disclosure by firms in these industries is also low. The government or industry associations can promote the disclosure of carbon information by firms in these industries by developing industry carbon information disclosure guidelines or standards.

Thirdly, local governments should formulate differentiated policies to guide firms to actively disclose carbon information. Due to the uneven distribution of regional economic development and industrial structure in China, firms in different regions have different sensitivities to the same factor that affects carbon information disclosure. So there are differences in the quality of carbon information disclosure among firms in different regions, even within the same industry in different regions. Therefore, during the transitional period before the implementation of mandatory carbon information disclosure policy for all listed firms, local governments and financial institutions such as banks should formulate differentiated policies based on local economic conditions and industrial structures to guide and encourage local listed firms to actively disclose carbon information. For example, in Hubei, where the quality of carbon information disclosure is relatively low, local banks can introduce relevant policies to encourage and guide local listed firms to disclose more carbon information. For Liaoning, which rarely discloses carbon information in industries such as mining industry, real estate industry, and scientific research and technical service industry, local government can introduce relevant policies to encourage and guide listed firms in these industries to actively disclose carbon information.

Fourthly, listed firms in China should further improve their corporate governance structure to promote the improvement of the quality of carbon information disclosure. Listed firms in China should establish an environmental committee or ESG committee to enhance corporate environmental responsibility awareness, improve the effectiveness of environmental and climate-related decisions, promote corporate green transformation, and thus promote the improvement of the quality of carbon information disclosure. In addition, listed firms in China should further improve board independence by appointing more independent directors to ensure the fairness and transparency of firm decisions, promote the firm to better fulfill its social responsibilities, and thus promote the improvement of the quality of carbon information disclosure.

5.3 Limitations and Future Research

This study has some limitations as well as future research implications: First, considering the impact of the pandemic on firms' carbon information disclosure, the sample period of this study is from 2015 to 2019. Due to the impact of the pandemic, firms may pay more attention to their own survival and development from 2020 to 2022, and will handle carbon information more cautiously, worrying that carbon information disclosure will have an adverse impact on firms. Therefore, firms lack motivation to disclose carbon information during this period. For example, although the business operations in 2019 were not affected by the pandemic, some firms were already affected by the pandemic when the carbon information of 2019 was disclosed in 2020. The quality of carbon information disclosed by listed firms in Hubei, Hainan, Tianjin and Shanghai in 2019 was lower than that from 2015 to 2018. With the economic recovery after the pandemic, the number of samples that have not been disturbed by the pandemic will increase. Future studies can expand the sample period after the pandemic to further test the empirical results of this study.

Second, this study takes listed firms in ten provincial-level administrative regions in China's low-carbon pilot provinces and cities as a sample. Although the distribution of these ten provincial-level administrative regions covers the south, northeast, middle, northwest, southwest, north and east of China and can reflect the carbon information disclosure situation of firms in various regions of China in a relatively comprehensive manner, it may not fully represent the average level of carbon information disclosure of firms in various regions of China. In the future, the research sample can be extended to listed firms in all provincial-level administrative regions in China to better reflect the carbon information disclosure quality of firms in various regions of China.

Third, this study selects factors that affect firms' carbon information disclosure from three perspectives: external environment, stakeholders, and corporate governance, and aims to explore the differences in the influencing factors of the quality of firms' carbon information disclosure in different regions. However, there are many other factors that affect the quality of firms' carbon information disclosure. In the future, research can be expanded to test the impact of more influencing factors on the quality of firms' carbon information disclosure in different regions. For example, the quality of firms' carbon information disclosure in the central and western China is not sensitive to some factors in this study. Future research can further explore which factors can promote firms' carbon information disclosure in central and western China.

Fourth, the measurement of carbon information disclosure quality in this study is an index composed of evaluation indicators. Although this index can reflect the quality of carbon information disclosure in a relatively comprehensive manner, it cannot cover all carbon information disclosed by firms. In the future, various measurement methods can be used to measure the quality of firms' carbon information disclosure.

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