Carbon risk management and corporate competitive advantages

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Abstract: Emerging economies such as China not only enjoy the development dividend generated by economic expansion, but also face the urgent problem of firm transformation before the worsening environmental problems. Therefore, this paper empirically demonstrates the influence of carbon risk management on corporate competitive advantages. We find that the relationship between carbon risk management and corporate competitive advantages is a "kuznets curve" that exists only among firms with weak product competition. And this relationship tends to be weakened in firms with a distant administrative hierarchy. We conclude that the influence of low carbon management on corporate competitive advantages is complicated and subject to the firm's political relevance.

Key words: Carbon risk management, competitive advantages, administrative hierarchical distance, sustainable development strategies, resource-based view.

1 Introduction

Since the time that China's economic development entered a new normal stage, A rapid changing business environment has become a "tiger in the road" that is holding up the development. Whilst providing the possibility for firms to obtain excellent performance is just one part of the puzzle, it becomes equally crucial to establish a strategic common sense in making business decisions. A firm is claimed (Amit, 1993) to struggle to sustain steady and sound development or to gain competitive advantages in its industry without effective strategies. Existing research indicates that corporate competitive advantages come from the heterogeneity of the specific components of the company, such as intellectual capital, innovation, dynamic capabilities, institutional resources (Villalonga, 2004; Barrett & Sexton, 2006; Pandza & Thorpe, 2009; Hsu & Wang, 2012; Li & Chen, 2012), as well as environmental performance(Yadav et al., 2017); whereas these studies rarely explore the impact of carbon emission management heterogeneity on corporate competitive advantages, suggesting a gap in contemporary literature. As a global-wide and irreversible environmental issue, the consequence of carbon emission calls for carbon management, which requires companies to invest in specific resources and government's compliance with carbon management requirements is more demanding (Liao et al., 2015). Therefore, this paper is seeking to contribute to fill in this gap by looking at the influence of environmental performance on corporate competitive advantages.

Carbon emission reduction has been a hot topic for social discussion for many years. *The UN 2030 Agenda for Sustainable Development* states that taking urgent action to address climate change and its impact is one of the world's 17 United Nation's Sustainable

Development Goals (UNDP, 2017). Yet, the research filed of whether companies can obtain competitive advantages through internal carbon risk management in a complex and changeable environment is rather under established, especially in an emerging economic context. Some studies (Friede et al., 2015; Servaes & Tamayo, 2017) do recognize the level of carbon risk management as an important factor that affects the competitiveness of a country at a national level, without explicit illustrations on this factor affecting competitive advantages at the company level. Conflict resolution theory (Jo & Harjoto, 2011; Servaes & Tamayo, 2013) suggest carbon risk management activities can help companies gain competitive advantages in the market by alleviating the conflict of interest between managers and non-investment stakeholders, which may also improve corporate reputation and profitability. Yet, such an approach is seen as costly from over investment theoretical perspectives (Servaes & Tamayo, 2017) that companies are prone to over-investment, especially in difficult economic times. Nonetheless, both contradictory views suggest the necessity of investigating the correlation between carbon risk management and corporate competitive advantages. It will help the company make the right decision. Moreover, considering the characteristics of China's political decentralization, the relationship between carbon risk management and corporate competitive advantages may also be affected by the administrative hierarchical distance because the government of China has the power to redistribute the resources for business development (Chang & Wu, 2014).

Empirically, starting from the resource-based view, we demonstrate the influence of carbon risk management on corporate competitive advantages by using a mixed regression model to analyze data from 279 Chinese A-share listed companies in the Shanghai and

Shenzhen Stock Exchanges from 2012 to 2017. This paper contributes to the following aspects: (1) Based on the particularity of China's political decentralization, this paper empirically reveals the changing trend of corporate competitive advantage under different levels of administrative hierarchical distance so we can learn more about the role of government in corporate environmental practices. (2) This paper combines external market factors to explore the impact of carbon risk management on competitive advantage in different scenarios of product competition, so as to help companies identify their own positions and develop and adjust their development strategies. (3) This paper makes an extensive contribution based on Yadav et al. (2017) by analyzing the low-carbon choice between differentiation and the cost-leadership strategy by integrating the resource-based and the dynamic capability theory into the same research framework (Wu, 2010), and it opens a "black box" that considers how carbon risk management would affect corporate competitive advantages from a new perspective.

The paper is structured as following. In the next section, we review the contemporary literature together with our theoretical analysis and describe our hypothesis development. We then present the research design, including sample selection, data sourcing, variable measurements and model design to empirically demonstrate the impact of carbon risk management on corporate competitive advantages. Finally, we present a discussion of our findings, draw conclusions and explore the potential implications of this study.

2 Literature review and Research Hypotheses

Huang et al. (2015) stated that the firm's competitive advantages commonly depend on the exogenous force (IO perspective) caused by the market position, and the endogenous power

generated by the resources and capabilities of the company (RBV perspective). According to the theory of industrial organization (Jean, 1988), the higher the market position of a company in the external market, the greater the market share that company can obtain. The resource-based view (Lee & Kim, 2011; Forsman, 2013) claims that differentiated resource endowments can be transformed into the unique capabilities of the company. If other companies want to copy such resources or capabilities, they will have to pay high copying costs, which are often called "Ricardian Rents" (Wernerfelt, 1989); this allows the leading company to earn extra compensation and gain a certain competitive advantage. However, well-developed enterprises need to pay more attention to the accumulation of superior resources or capabilities in the course of their subsequent development, due to the existence of the "Matthew effect" (Robert, 1968). If leading companies are successful in efficiently updating and integrating superior resources, they will remain far superior to other companies, resulting in "Schumpeterian Rents" (Teece et al., 1997). In other words, where carbon emissions in China are increasingly valued, companies are primarily engaged in carbon risk management to help them consolidate their existing market positions and acquire differentiated resources and capabilities while catering to existing policies. Reasonable carbon risk management can provide an effective source of corporate competitive advantages, especially when the relationship between environmental risk and commercial risk is gradually obvious, and the external result of this advantage is specifically reflected in the improvement of corporate profitability.

Based on that, research has been conducted on the mechanism of the influence of corporate competitive advantages. For example, Villalonga (2004) pointed out that the correct business strategy can create valuable resources for enterprises. In particular, intangible

resources can not only make outstanding contributions to corporate competitive advantages, but also quickly land a company in trouble with improper selection. Choi & Wang's survey (2009) suggested that competitive advantages could be achieved by maintaining a good relationship with stakeholders, which helped to accumulate potential network resources known as 'Guanxi' for corporations. Hsu & Wang (2012) investigated the impact of intellectual capital (such as human, structural and social capital) on corporate competitive advantages, with the discoveries that each type of capital can bring excellent performance advantages to companies. Given an understanding of the antecedents of competitive advantages, other scholars have become more inclined to study the dynamic performance and sustainability of competitive advantages (Wiggins & Ruefli, 2002; Huang et al., 2015; Yadav et al., 2017). It is claimed (D'Aveni et al., 2010) that corporate sustainable competitive advantages can be achieved through a series of temporary competitive advantages by adjusting for the dynamic capabilities, with the conclusion that the higher the company with a market position, the greater the temporary competitive advantages the company would have, and thus the better the superior results converted from these advantages are. Moreover, product competition is also an important governance mechanism that is conducive to gaining competitive advantages. Consumers pay more attention to the quality of a product and its practical functions (Biswas & Roy, 2015), so the market for companies with a high product market competition tends to be saturated, and it's difficult to obtain obvious advantages through environmental management but only play a role of maintain.

With the increasing public awareness of environmental protection, a nature resource-based view has been proposed that includes three strategic dimensions, namely pollution

prevention, product management and sustainable development. This provides a more systematic theoretical support for the relationship between environmental and corporate performance (Mao et al., 2017). Pollution prevention and product management are important ways for companies to achieve sustainable development (Grzebyk & Stec, 2015). The nature resource-based view conveys that the development of a company depends primarily on the natural environment, and corporate competitive advantages depend on the economic viability of sustainable development (Hart, 1995). Correspondingly, people have expressed increasing interest in "strategic corporate social responsibility" and have investigated the specific actions of firms in terms of social responsibility (McWilliams& Siegel, 2001). This approach seems to generate certain social benefits and allow companies to improve their performance. Corporate social responsibility (hereafter CSR) is the best way for companies to "do good things", but it is still mainly a strategic choice. By providing a framework for non-market strategies, Dorobantu et al. (2017) argue that social responsibility should be considered as an operating method in the face of inadequate existing rules or legal protection, and as such, CSR can help companies pursue competitive advantages. Kaul et al. (2018) construct an economic model of CSR, suggesting that a socially responsible policy can generate additional profits when a company's efforts can be distinguished from non-profit organizations and are closely related to its core business.

In general, the literature has studied CSR from various aspects, but it also reminds us of the basic issues that all companies face from a "strategic" perspective: a differentiation strategy or a cost-leadership strategy? Differentiation and cost-leadership are seen (Porter, 1985) as two major components of competitive advantages, with subsequent research focus on CSR as a tool

to highlight competitive advantages. Yadav et al. (2017) found that improved environmental performance can help companies maintain their competitive advantages and compensate for poor performance. Similarly, Flammer (2018) identified that companies with better environmental performance can strategically increase the competitiveness of the government procurement contract market −15%-20% of America's GDP (World Trade Organization, 2014). Conversely, Ioannou & Seraeim's (2012) CSR study indicates otherwise, that companies with fierce market competition may have worse CSR performance, which is the choice that companies make to survive in the face of meagre profit margins. In this case, it is possible to cut corners and save money when companies are carrying out social responsibility activities, reflecting the cost-leadership strategy for profit and tending toward "corporate irresponsibility". In addition, there are many studies that study only the influence of internal factors or external factors on competitive advantages (Hsu & Wang, 2012; Yadav et al., 2016; Manchiraju & Rajgopal, 2017), but the strategic choice of companies is also vulnerable to the "interference" of product competition, as the competitiveness of products directly affects the costs and benefits of companies (Meng et al., 2016). We therefore argue that the relationship between carbon risk management and corporate competitive advantages will be reflected in different strategic environments, so a one-sided discussion cannot effectively clarify the relationship between the two while the economy of China is in the "new normal".

To sum up, it can be understood from the contemporary literature that the impact of environmental performance on corporate competitive advantages is seen as vague (Martinez-Ferrero & Valeriano Frias-Aceituno, 2015; Bendell & Nesij, 2018), which may be related to the different definitions of CSR. This paper adopts the concept of carbon risk management as

a typical mean of CSR to analyze the impact of "strategic CSR" on corporate performance from the perspective of low-carbon management and we define carbon risk management as a management model that runs through the production and operation processes of a company, taking environmental impact and resource utilization into full consideration.

2.1 Carbon risk management and corporate competitive advantages

Carbon risk causes great uncertainty in the process of enterprise development, and this uncertainty will become increasingly prominent as climate problems intensify (Zhou et al., 2018). Therefore, carbon risk management, as an effective strategy for promoting CSR and enhancing competitive advantages, is an important manifestation of how enterprises have been responding to the low-carbon era. Yet, the relationship between carbon risk management and corporate competitive advantages can be demonstrated in various means according to the previous literature review (Servaes & Tamayo, 2013; Servaes & Tamayo, 2017). Therefore, this paper proposes alternative hypotheses H1a and H1b from the perspective of cost leadership and differentiation for the main effects.

The resource-based view claims that the factors of choice, accumulation and use of resources are driven by the considerations of efficiency, effectiveness and profitability (Conner, 1991), while the ability of firms to gain competitive advantages depends on what barriers to critical resources may exist (Amit, 1993). Enterprises tend to have the ability to dynamically integrate static resources to match the changing characteristics of the current market. We find that enterprises that conduct carbon risk management are more likely to gain competitive advantages, since the knowledge used in carbon risk management activities has the characteristics of internal structure fuzzification(Wohlgemuth & Wenzel, 2016). The company

can continuously update its internal knowledge on the original basis of its resources, which eventually leads to the continuous improvement of the replication threshold to encourage positive feedback of dominant companies. Whilst we recognize the potential increase of the agency cost and the potential compliance cost of the company with the emergence of carbon risk that may hinder the endogenous growth potential of the company, the production process can be improved to develop the environmental adaptation of the company through carbon risk management, leading to further reduction of the cost of energy, the demand for materials and labour, and even the total cost of production (Zeng et al., 2010). That is, incorporating carbon risk management into corporate strategies can improve enterprise resource utilization and business performance by optimizing internal production processes and departmental collaboration. Companies are constantly introducing new technologies or equipment during their pursuit of carbon risk management, which can help companies improve their innovation capabilities and promote the establishment of competitive advantages based on innovation and operations (Mao et al., 2017). In this way, carbon risk management requires companies to make extra efforts to improve their production processes such as the purchase of environmental equipment and the training of employees; however, a company's green practices can improve efficiency and reduce production costs, giving employees a higher sense of belonging. The resulting return may generate benefits for the company (Murillo-Luna et al., 2011) in terms of creativity and business efficiency. Moreover, investment in carbon risk management has increased the "imitation barriers" of other companies, as carbon risk management activities are difficult for competitors to copy (Lee & Kim, 2011; Forsman, 2013).

By incorporating the stakeholder's environmental views into the resource-based view,

management's internalization of the environmental aspirations of shareholders in the decision-making process is conducive to catering to current environmental concepts and creating a positive corporate image (Jo & Harjoto, 2011; Servaes & Tamayo, 2013). Corporate social reputations are likely to include intangible resources, which are conducive to attracting high-quality resources from society and helping to enhance corporate value. Efficient low-carbon practices can enhance a company's market position, increase revenue, reduce costs (Zhou et al., 2018) and drive positive stock returns that reduce the company's cost of capital (Yadav et al., 2016), whereas the diversification of product attributes and consumer preferences (Foellmi & Zweimuller, 2004; Conrad, 2005) creates space for the implementation of differentiation strategies. By presenting product attributes in different combinations, companies can effectively distinguish themselves and their products, and the diversification of consumer preferences caused by income, education, taste and other aspects can be used to create products with different attributes. It has been found in the literature (Conrad, 2005; Ghosh & Shah, 2012) that a company's environmental efforts can provide additional "properties" (such as being green, or low-carbon) that cater to the increasing environmental needs of consumers, thereby enhancing the attractiveness of corporate products in the marketplace. In conclusion, effective carbon risk management provides the possibility of acquiring competitive advantages, regardless of internal management optimization or external product market. This paper therefore proposes hypothesis 1a from the perspective of differentiation.

H1a: Carbon risk management helps firms gain competitive advantages.

However, studies on "strategy-performance" often have contradictory results. Whilst studies suggest that differentiation strategies do gain competitive advantages for companies,

some studies show that enterprises that emphasize cost-leadership strategies can often occupy more competitive advantages in the market (Fernandez-Kranz & Santalo, 2010; Biswas & Roy, 2015). The latter is supported by China's recent development, in which most companies adopt cost-leadership strategies in their development that rely on cheap labour and production costs to gain considerable international competitive advantages (Murray et al., 2005). To a large extent, this result depends on consumers paying more attention to the price of a product and its practical functions (Biswas & Roy, 2015), indicating that the implementation of a company's differentiation strategies will be difficult when consumers are not concerned about low-carbon attributes. In addition, the awareness of intellectual property protection has also been found weak in most developing countries such as China (Strizhakova et al., 2008; Berrone et al., 2013), evidenced by numerous copycat products in the market. Thus, the product value attributes that differentiation strategies want to convey cannot provide attractiveness, and consumers' purchasing intentions directly lead to a company's tendency to abandon "green" differentiation. On the one hand, companies that exceed the industry's expectations to take the lead in implementing environmental protection strategies may be resisted by their peers and they may be driven to consider survival issues instead (Bansal & Roth, 2000). On the other hand, carbon risk management requires a large investment of financial, human and technical resources, as well as the long-term strategic commitments of shareholders, boards of directors and management (Le et al., 2013), which opens up the possibility of a differentiated strategy and, simultaneously, the priority factor for companies in choosing a cost-leadership strategy. The "shareholder burden" view (Manchiraju & Rajgopal, 2017) holds that companies monopolize the moral hazard cost of corporate wealth when they invest in the environment.

Therefore, this paper puts forward hypothesis 1b from a cost-leadership perspective.

Hypothesis 1b: Carbon risk management does not create competitive advantages.

2.2 Moderating effect of administrative hierarchical distance

Unlike other countries that government of China is a regulator in economic development with a multiple administrative hierarchy, each of which may have different impacts on corporate behaviors (Chang & Wu, 2014). Studies (Li & Zhou, 2015; Dong et al., 2016; Luo et al., 2017) have shown that companies with political connections enjoy many advantages in terms of bank loans, financial subsidies and tax breaks, with significantly better corporate performance than those without political connections. In addition, companies are extremely vulnerable to the drag of imperfect market mechanisms in the development process. The government's intervention can provide effective shelter for enterprises to reduce their troubles and improve their operational efficiency, so as to enhance corporate value. Wang et al. (2018) identified that government in the era of China's decentralization system has multiple features in local development targets, so there are differences in policy implementation at different administrative hierarchical distances, leading to different development results. Therefore, based on the resource-based view, the greater the administrative hierarchical distance, the easier it is for companies to obtain necessary information resources, technical resources and institutional resources in the development process, and to make rapid adjustments according to market changes to reduce losses. For example, the central enterprises' sensitivity to national policies is significantly better than other companies because its administrative hierarchical distance is greater than others. Yet, the theory of the reciprocal exchange of social capital (Li et al., 2012) suggests that the government provides enterprises with various resources, but also

has expectations for enterprises to give back to society and raise the legal requirements of environmental protection for companies. Therefore, as pioneers in the reform of high-energy-consumption enterprises in China, those companies that enjoy close connections with government can enjoy policy support that makes up for the disadvantages brought by cost and by the increase in the cost of fending off imitation by other enterprises. Due to the "inverse distance paradox" that exists in China's government, the closer the administrative hierarchy of the firm is to the top level, the higher the social trust that can be obtained, and the lower the cost of stakeholders' interpretation of the information that enterprises publish; all of these factors help companies obtain competitive advantages (Lin, 2018). Therefore, this paper proposes hypothesis 2a and hypothesis 2b based on H1.

Hypothesis 2a: With other conditions unchanged, the administrative hierarchical distance strengthens the beneficial impact of carbon risk management on corporate competitive advantages.

Hypothesis 2b: With other conditions unchanged, the administrative hierarchical distance weakens the negative impact of carbon risk management on corporate competitive advantages.

<Insert Figure 1 here>

3 Research design

3.1 Sample and data

Our sample span is set to the years 2012-2017 in view of the fact that the Chinese government officially adopted the goals of a green economy and a low-carbon economy as strategic priorities in the 12th "Five-Year Plan" in 2011, and the growth rate of national GDP began to

fall in 2012. The research object is a group of A-share listed companies on the Shanghai and Shenzhen Stock Exchanges. Due to the lag of carbon risk management on corporate advantage, the total sample size was determined based on all firms that issued social responsibility or sustainable reports between 2012-2016.The criteria for continuous screening processes includes: (1) Subtract the companies with at least one year of financial data missing between 2013 and 2017; (2) Subtract the companies listed as belonging to the financial industry; (3) Subtract the companies that were listed in the relevant stock exchanges before 2012; (4) Subtract the companies that were listed on the special treatment list between 2012 and 2017; (5) To avoid extreme values leading to more discrete samples, winsorize processing was carried out on all continuous variables at l% and 99%. Finally, 279 sample companies were obtained with a total of 1,395 sample observations; most of these companies were distributed in the manufacturing industry and the power and thermal production and supply industry. The sample screening process and industry distributions are shown in Table 1 and Table 2.

<Insert Table 1 here>

<Insert Table 2 here>

The main data sources used in this paper are as follows. (1) The initial data of carbon risk management came from Juchao: http://www.cninfo.com/ and Hexun: http://www.hexun.com, including the annual reports, social responsibility reports, annual environmental impact reports and sustainability reports, which were collected and organized by the author manually. (2) All financial data was derived from the RESSET database and the CSMAR database. We analyzed the data using Stata 13.1 and Eview8.0.

3.2 Variables

3.2.1 Dependent variable

Based on the study of Wu (2007) and Yadav et al. (2017) on corporate competitive advantages, this paper defines corporate competitive advantages as having the characteristics of being superior to other competitors under the influence of internal and external factors. The return on assets (ROA) metric can provide the overall performance of the company and comprehensively reflect the impact of strategic changes (Choi & Wang, 2009; Clarkson et al., 2013; Alshehhi et al., 2018). Therefore, model (1) is used to measure corporate competitive advantages according to the definition (Villalonga, 2004). ΔROA_t represents corporate competitive advantages, ROA_t represents the return on assets of the company, and ROA_{Ind_mean} represents the average return on assets of the industry.

$$\Delta ROA_t = ROA_t - ROA_{Ind\_mean} \quad (1)$$

3.2.2 Independent variables

As for the indicators of carbon risk management, China has not established a mature carbon information database, and the public annual reports, social responsibility reports and other data information has not been clearly disclosed. Foreign (non-Chinese) scholars tend to use the KLD or CDP databases for research (Delmas et al., 2013; Tauringana & Chithambo, 2015). Therefore, drawing on the practices of Boettcher and Mueller (2016) and Haque (2017), we used *the Carbon Risk Management Index* and the *CDP 2017 Climate Change Questionnaire* to measure corporate competitive advantages. We considered a total of 12 items, and the scale is

shown in Table 3. *The Carbon Risk Management Index* represents the management level of a company in the process of controlling carbon risk. If the sample company discloses certain carbon risk management information, the value is 1. Otherwise, the value is 0, and then the index is obtained after the sum. The larger the index, the higher the carbon risk management level of the sample companies. Since the research samples involve a large amount of text analysis, this paper uses qualitative analysis software NVivo11 to query and count the source reports mentioned above. Incomplete information and text displayed in the form of pictures were collected by hand, including chapters on social responsibility management (goals and strategies of social responsibility, etc.), protection of rights and interests of suppliers, customers and consumers (green procurement, green industrial chain, etc.), environmental protection and sustainable development.

Administrative hierarchical distance indicates the level of the government that has an direct impact on the company, which reflects the level of supervision and control over the established company that the government may hold (Wang et al., 2018). This paper does not use the inherent paradigm of corporate property rights as a moderating variable (Zhou et al., 2018)，but subdivides the case study listed companies into five types according to the ultimate controller data of the company according to the "ultimate property rights theory", and uses the values 1 to 5 to calculate the distance (Li et al., 2018; Wang et al., 2018). If the company is controlled by the central government, the value is 5; if the company is controlled by the provincial government, the value is 4; if the company is controlled by the municipal government, the value is 3; if the company is controlled by the county government, the value is 2; if the company is not controlled by any level of government, the value is 1.

<Insert Table 3 here>

3.2.3 Control variables

Referring to the research of Liu et al. (2014), Haque (2017), and Macaulay et al. (2018), the financial resources and management resources of companies in addition to environment resources have an important impact on corporate competitive advantages. Companies with strong financial resources, governance structure and management capabilities are often more competitive in the market. In addition, the existence of independent directors can play a role in monitoring corporate decisions, especially in the company's green practices. Therefore, this paper has the necessary control over these points and also controls some of the regular features of the company. The control variables selected in this paper include Firm Size (*Size*), Financial Leverage (*Lev*), Organization Slack (*Slack*), Ratio of Independent Directors (*Bi*), Capital-intensity (*Cap*), Ownership (*Own*), Firm Age (*Age*), Region (*Reg*), Industry (*Industry*) and Year (*Year*). The specific variables are defined in Table 4.

The existence of independent directors can play a role in supervising corporate decision-making, especially in the company's green practice. Therefore, the variables selected in this paper include company size, financial leverage (Lev), organizational redundancy (Slack), and independent director ratio (BI). Capital intensity (Cap), ownership (Own), enterprise age (Age), region (Reg), industry (Industry), year (Year), etc. are the control variables of this study, and the specific variables are defined in Table 4.

<Insert Table 4 here>

3.3 **Models**

The panel data model from 2012 to 2017 was selected in this paper to eliminate the sequence correlation and heteroscedasticity problems that are common when using cross-sectional data or time series data, and to avoid endogenous problems caused by missing variables which can effectively reduce the bias of the empirical results. In addition, the mixed effect model was adopted to analyze the sample.

To verify hypothesis H1 and study the impact of carbon risk management on corporate competitive advantage, this paper constructs model (2) for empirical testing:

$$\Delta ROA_{i,t} = \alpha_0 + \alpha_1 \times CRC_{i,t-1} + \alpha_i Control_{i,t} + \varepsilon_{i,t} \quad (2)$$

In order to verify hypothesis H2 and study the moderating effect of the administrative hierarchical distance, this paper constructs model (3) for empirical testing:

$$\Delta ROA_{i,t} = \beta_0 + \beta_1 \times CRC_{i,t-1} + \beta_2 \times Gov\_dis_{i,t} + \beta_3 \times CRC_{i,t-1} \times Gov\_dis_{i,t} + \beta_i Control_{i,t} + \varepsilon_{i,t} \quad (3)$$

Considering that the impact of carbon risk management on corporate competitive advantages has a certain hysteresis, this paper processed the data with a lag of one period to help alleviate the endogenous problems among variables. $CRC_{i,t-1}$ represents the level of carbon risk management in the previous period of the company; $\Delta ROA_{i,t}$ is the firm's competitive advantage in this period; $Gov\_dis_{i,t}$ is the administrative hierarchical distance; α_0 and β_0 are constant terms; α_1、α_i and β_1、β_2、β_2、β_{2i} are the coefficients of each variable; $\varepsilon_{i,t}$ is the residual term while *i* is the sample object; and *t* is the year.

4 Empirical results

4.1 Descriptive statistical analysis and correlation analysis

Table 5 provides descriptive statistics for the data of all variables used to study corporate competitive advantages, providing us with a preliminary understanding of the relationship between carbon risk management and the firms' competitive advantages. Descriptive statistics show that the mean of corporate competitive advantage is -0.0001, the standard deviation is 0.0419, the minimum and maximum values are -0.115 and 0.141, and the median is -0.00472, indicating that the overall competitive advantages of the sample firms are low, and the annual change in performance is relatively stable. However, most companies are at a disadvantageous position compared to the mean and median, which is roughly consistent with the *status quo* of the industry, indicating that companies are facing the urgent need for low carbon transformation. The maximum value of the carbon risk management index is 10, while the minimum is 0, and the average value is 4.135, suggesting that the carbon risk management of sample firms is still at a low level in general; whereas the performance of individual firms is slightly different. The impact of risk has not attracted significant attention, or the firm has underestimated the impact of carbon management. The average value of the administrative hierarchical distance is 2.86, and the standard deviation is 1.65, indicating that the administrative distance of each firm has certain differences, and the sample companies are mainly controlled at the level of the municipal government or below. Descriptive statistics of other control variables are shown in Table 5, and thus will not be repeated here.

<Insert Table 5 here>

Table 6 provides a correlation analysis of all variables used to study corporate competitive advantages to determine whether multiple collinearity exists in the research model. The upper triangle is the Spearman correlation test, and the lower triangle is the Pearson correlation test. Combining these two methods can improve the credibility of the correlation analysis. The analysis results show that carbon risk management (CRC_{t-1}) is negatively correlated with corporate competitive advantages (ΔROA_t), which indicates that carbon risk management is not conducive to maintaining corporate competitive advantages to some extent and provides preliminary evidence with low significance for hypothesis 1b. Results still need to be verified by the model below. Apart from the fact that the coefficients of the *Administrative hierarchical distance* (*Gov-dis*) and the *Ownership* (*Own*) factors are both greater than 0.8, the other variables are within the normal range (less than 0.5), indicating that there is no serious collinearity problem. On this basis, the variance inflation factors (*VIF*) of the regression model in this study have been tested and found to be less than 10, which can be used to posit that there is no possibility of serious multiple collinearity in the model (Lennox et al., 2012; Tsalavoutas et al., 2012; Clacher et al., 2013).

<Insert Table 6 here>

4.2 Main effect results

This paper first performs a regression test on the full sample application model (2) to verify hypothesis 1, with the results shown in Table 7, suggesting that the coefficient of CRC_{t-1} in the regression results of the full sample is -0.0000, which is consistent with the results of hypothesis 1b but fails to pass the significance test of 10%. This means that the assumptions and models put forward in the previous paragraph cannot be reasonably explained, and the

linear relationship cannot fully explain the mechanism of action between carbon risk management and corporate competitive advantages. We suspect that carbon risk management may have a nonlinear impact on corporate competitive advantages under a political and economic environment with China's current characteristics and aim to verify it.

<Insert Table 7 here>

Based on the above analysis, there may be various complicated relationships between carbon risk management and corporate competitive advantages. Firms with strong competitive advantages may make more prominent efforts toward carbon risk management, and may also operate below normal conditions (Brammer & Millington, 2008). Therefore, this paper refers to the quadratic terms of carbon risk management to reconstruct a new model (4) to study the nonlinear relationship between carbon risk management and corporate competitive advantages according to the practice of Zhou et al. (2018).

$$\Delta ROA_{i,t} = \alpha 0 + \alpha 1 \times CRC_{i,t-1} + \alpha 2 \times {CRC_{i,t-1}}^2 + \alpha_i Control_{i,t} + \varepsilon_{i,t} \quad (4)$$

Table 8 provides the regression results of model (4). As shown from the results, the fitting degree of the non-linear model (4) is better than that of the linear model (2). That is, compared with the previous linear model, the carbon risk management quadratic term model is more convincing in explaining the relationship between carbon risk management and corporate competitive advantages. To be specific, the coefficient (0.0026) of CRC_{t-1} is significantly positive at the level of 10%, while the coefficient (-0.0004) of CRC_{t-1}^2 is significantly positive at the level of 5%, indicating that the impact of carbon risk management on corporate competitive advantages is not a monotonous increase or decline. On the contrary, when the

value of this correlation is lower than 4.33, carbon risk management is positively correlated with corporate competitive advantages. When the value is higher than 4.33, there is a negative correlation between carbon risk management and corporate competitive advantages. In summary, there is an inverted u-shaped relationship between carbon risk management level and corporate competitive advantages.

<Insert Table 8 here>

4.3 Moderating effect results

Based on the constructed model (4), this paper, by introducing the interaction of the quadratic terms of carbon risk management and administrative hierarchical distance, constructs the following model (5) to empirically test the moderating effect of administrative hierarchical distance on the relationship between carbon risk management and corporate competitive advantages.

$$\Delta ROA_{i,t} = \beta_0 + \beta_1 \times CRC_{i,t-1} + \beta_2 \times CRC_{i,t-1}^2 + \beta_3 \times Gov\_dis_{i,t} + \beta_4 \times CRC_{i,t-1} \times Gov\_dis_{i,t} + \beta_5 \times CRC_{i,t-1}^2 \times Gov\_dis_{i,t} + \beta_i Control_{i,t} + \varepsilon_{i,t} \quad (5)$$

From the regression results in Table 9, it can be seen that the coefficient (0.0003) of the interaction is significantly positive at the 5% level. This shows that the administrative hierarchical distance weakens the inverted U-shaped relationship between carbon risk management and corporate competitive advantages, and hypothesis 2b is therefore verified.

<Insert Table 9 here>

4.4 Further analysis

Considering that the graph can more intuitively display the relationship of this study, this paper

constructs the curve shown in Figure 2 based on the regression results. The solid line indicates the main effect curve of carbon risk management and corporate competitive advantages, which has the overall appearance of an inverted U-shape, but the curve's opening is large. The dotted line represents the change trend of the moderating effect. When *Gov-dis*=1, the opening of the inverted "U-shaped" curve is the smallest. With the increase in the administrative hierarchical distance, the curve gradually flattens out. However, when *Gov-dis* > 4, the relationship between carbon risk management and corporate competitive advantages begins to show a "U-shaped" curve. Therefore, the inverted U-shaped relationship between carbon risk management and corporate competitive advantages first weakens and then improves? is strengthened? with the involvement of the administrative hierarchical distance.

<Insert Figure 2 here>

To explain the impact of carbon risk management on corporate competitive advantages in a more detailed way, this paper conducts a group test according to the level of product competition which measured by profit margin of main business (Jiang et al., 2008). It then divides the sample into a strong product competition group and a weak product competition group relative to the average value of product competition. The results are shown in Tables 7, 8 and 9.

The results shown in Table 7 provide indirect evidence that the linear relationship between carbon risk management and corporate competitive advantages is not established. The results in Table 8 show that the coefficients of CRC_{t-1}^2 (-0.0000) and CRC_{t-1} (0.0017) in conditions characterized by strong product competition are not significant, while those in conditions of weak product competition are both significant at the 10% level. This indicates that corporate

competitive advantages depend on the competitiveness of the products themselves when the product competition is strong and the role of carbon risk management in these companies is weak. When the company's product competition is weak, the change in competitive advantages caused by product defects can be compensated for by appropriate carbon risk management. Table 9 provides data regarding the moderating effect of the administrative hierarchical distance under different levels of product competition. The results are similar to the group test of the main effect, which demonstrate that the administrative hierarchical distance has little effect if corporate product competition is strong. When the product competition of a firm is weak, the coefficient (0.0003) of the interaction between administrative hierarchical distance and the carbon risk management quadratic item is significant at the 10% level, which weakens the relationship of the main effect, providing evidence for hypothesis 2b. Figure 3 shows the relationship between carbon risk management and corporate competitive advantages in conditions of weak product market competition, from which it can be seen intuitively that the curve under conditions of weak product market competition is roughly similar to the curve of the full samples. This indicates that the moderating effect of administrative hierarchical distance on carbon risk management and corporate competitive advantages is U-shaped.

<Insert Figure 3 here>

4.5 Endogenous Control and Robustness Test

Although this study considers the impact of other variables on corporate competitive advantages, there are still endogeneity problems caused by factors such as missing variables. We draw on the approach of Jo & Na (2012) and introduce the lag term of corporate competitive advantages as the control variable to conduct another regression analysis,

considering that corporate competitive advantage is likely to be affected by its existing level. The test results of endogenous control are shown in Table 10. The competitive advantages in the t-1 period are significantly positively correlated with the competitive advantage in the t period. The other regression results are consistent with the previous ones, suggesting that the endogenous problem of the set model is some relief.

To enhance the reliability of the results, we also conducted a number of robustness tests. (1) We replaced the measure of carbon risk management. In order to improve the feasibility of carbon risk management measurement, it's might useful to use the alternative data sources (Haque, 2017) from *Chinese Research Data Services Platform* to do regression test. The results were found to be consistent with the previous conclusions fter the regression, as shown in Table 10. (2) We replaced the measure of corporate competitive advantages. Tobin's Q, which is considered to be a reliable indicator of corporate value (Custodio & Metzger, 2014), can reflect a value change in intangible assets, such as credit created by adopting a low-carbon management strategy. This paper selects Tobin's Q to replace the ROA for the regression analysis. The results remain basically unchanged as compared with the previous set in Table 8-9, and the test results are shown in Table 12. (3) We reduced the sample size and performed a re-regression. This study selected 250 manufacturing listed companies from all sample industries for a regression analysis according to the "*Industry Classification Guide for Listed Companies (2012)*". The results remained the same as in the above test, and these test results are shown in Table 13. (4) We increased or decreased control variables. By comparing the influence of control variables in the process of empirical analysis, this paper deleted the *Ownership* and the *Ratio of Independent Directors* for the re-regression. The results are shown

in Table 14, and they are found to be consistent with the original results.

<Insert Table 10 here>

<Insert Table 11 here>

<Insert Table 12 here>

<Insert Table 13 here>

<Insert Table 14 here>

5 Discussion

This paper takes a sample of the A-share listed companies in the Shanghai and Shenzhen Stock Exchanges as the research sample, empirically tests the mechanism of the impact of carbon risk management on corporate competitive advantage and obtains some unexpected findings.

The test results of H1 show that there is an inverted U-shaped relationship between carbon risk management and corporate competitive advantage, which is quite different from the findings of previous research on the impact of CSR (McWilliams & Siegel, 2001; Declerck & M'Zali, 2012) and of environmental performance (Martinez-Ferrero & Valeriano Frias-Aceituno, 2015; Yadav et al., 2016; Yadav et al., 2017) on the value of a company. This might be due to several reasons. Firstly, the massive international market for products that are "Made in China" continues to push companies to prefer a cost-leadership strategy, as consumers in developing countries are highly sensitive to prices; this means that "green" differentiation is becoming an adventurous strategic choice (Biswas & Roy, 2015). In contrast, the cost-leadership strategy has low requirements for social institutions and market institutional foundations. Thus, firms can increase market share and improve business performance at a low

cost in a decentralized industrial structure. Secondly, low carbon management activities have high economic externalities whereby managers are more willing to invest in projects with high returns instead of paying high costs for small profits. In addition, there is a lack of reliable information about the environmental performance of products in the market, and the current level of environmental awareness of consumers is not enough to "pay the bill" (Orsato, 2006), thus weakening a company's willingness to "go green". The *2018 Emissions Gap Report* issued by the *United Nations Environment Program* also provides some evidence that global carbon dioxide emissions have begun to grow after a three-year stabilization period. Thirdly, considering the impact of compliance pressures and corporate image on business performance, low-level carbon risk management is still thought (Choi & Wang, 2009) to help maintain a company's relationships with stakeholders and shape the image of being a responsible business, which may help companies obtain institutional and social resources in the future, although cost leadership might be the first preference for most companies.

However, this curvilinear relationship varies according to the level of administrative hierarchical distance. The results of H2 show that, on the whole, administrative hierarchical distance has a moderating effect on the weakening of carbon risk management and corporate competitive advantages, because the government has a significant amount of development resources (Luo et al., 2017). It is further identified that as the administrative hierarchical distance increases, the moderating effect assumes an inverted U-shape. This is due to the fact that the competition mechanism in China's political system is mainly based on economic performance, so local officials are forced to take economic development as their main target (Cull et al., 2017). Therefore, profitable heavy industry companies tend to enjoy the protection

of the local government (Marquis et al., 2011; Chang & Wu, 2014), and only low-level carbon risk management can achieve effective competitive advantages, because the high tolerance of a cost-leadership strategy strongly drives the rapid development of the enterprise. However, these advantages will disappear with the advancement of carbon risk management, because the firm's products will be replaceable, and the cost advantage will no longer matter. Accordingly, with the increase in the administrative hierarchical distance, the government gradually loses its "autonomy", its supervision power gradually increases (Wang et al., 2018), and the curve relationship is gradually weakened. In addition, companies are expected to carry out more CSR since the administrative hierarchical distance has increased to a certain extent, so they are more willing to choose a differentiation strategy to improve their competitive advantages based on the theory of the reciprocal exchange of social capital (Li et al., 2012). Yet, companies using differentiation strategies cannot compete with those using cost-leadership strategies in the market if they are less willing to conduct carbon risk management. Only a high level of carbon risk management can achieve competitive advantages, and this relationship is strengthened with the increase in the administrative hierarchical distance.

Furthermore, these correlations only exist in companies in conditions characterized by weak product competition. When the attributes of products have absolute advantages in the market, the company's market position is formed and other factors are insignificant (Bocquet et al., 2015). In other words, the result suggests the importance of innovation in the development process of companies, which enables us to derive accurate conclusions in the end.

6 Conclusions

This paper uses the data from a group of A-share listed companies on the Shanghai and Shenzhen Stock Exchanges during 2012-2017 by testing the impact of carbon risk management on corporate competitive advantages and discusses the moderating effect of administrative hierarchical distance, with the main findings being that the relationship between carbon risk management and corporate competitive advantages is a "kuznets curve" that only exists in enterprises that operate in markets characterized by weak product competition. When the level of carbon risk management is low, carbon risk management can promote corporate competitive advantages, while a high level of carbon risk management requires companies to sacrifice some of these competitive advantages. The relationship of the main effect is generally weakened by the level of administrative hierarchical distance. However, and interestingly, the moderating effect of administrative hierarchical distance is not a simple linear moderating relation, but is rather an inverted U-shaped relationship. That is, with the increase of administrative hierarchical distance, the moderating effect first weakens and then is strengthened.

This paper makes theoretical contributions by clarifying the relationship between carbon risk management and corporate competitive advantages from the perspective of resources and capabilities; this refines the existing research on environmental performance (Mao et al., 2017; Yadav et al., 2017) and expands the research perspective of low carbon management. In addition, this paper may contribute towards examining the differences in the role of administrative hierarchical distance and the influence of carbon risk management on corporate competitive advantage (Wang et al., 2018), which provides new evidence and a new perspective of how (and how much) the government influences corporate value. What is more,

the complex nonlinear moderating effect is transformed into the geometric change of the curve, which reveals the influence mechanism of the administrative hierarchical distance intuitively and provides a reference for subsequent research.

Similarly, this paper has brought some implications for business management. As compliance with carbon emissions restrictions increases in China, the adoption carbon risk management mode can help companies gain competitive advantages, despite the fact that the emergence carbon risk management might be time and cost consuming. The cost-leadership strategy has gradually lost its superiority in the Chinese market, but firms with a low administrative hierarchical distance may still adopt this strategy to improve the competitiveness of their product and increase the firm's vitality. That is to say, companies need to strongly support innovative development to improve the irreplaceability of their products (Liu et al., 2014). The government must give full play to its guiding function and pay more attention to those companies with lower administrative hierarchies, providing policy and financial support for carbon risk management so as to realize the smooth transition of enterprises into the new normal environmental and economic era.

This paper elaborates the low-carbon development status in Chinese business organizations with unique circumstances from other nations, with attempts to clarify the relationship between carbon risk management and corporate competitive advantages. However, this paper is inevitably limited by the following aspects. First of all, the research results cannot exclude the existence of a certain subjective bias, since there is no authoritative carbon risk management information disclosed in China, and relevant data was manually collected by the author. The data was collected by five people respectively and averaged in order to alleviate

the subjective bias. Secondly, the factor of competitive advantage of this paper is limited to temporary competitive advantage, which has not yet been extended to sustainable competitive advantage. Thirdly, this paper shows the inverted U-shaped moderating effect of the administrative hierarchical distance only in the form of graphs; the relevant relationship has not been verified by the model. Such a situation may suggest some future research agenda where further studies should be carried out in terms of examining the impact of different stages of carbon risk management on corporate competitive advantages and comparing the results internationally with the continuous compliance of carbon information disclosure data, as well as further distinguishing between temporary competitive advantages and sustainable competitive advantages.

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Tables and Figures:

Table 1 Sample companies screening process

Sample screening process	Number of companies
Issued a social responsibility report or a sustainable report between 2012 and 2016	418
Less: At least one year of financial data missing between 2013-2017	(0)
Less: Listed as a financial, financial industry	(108)
Less: Companies listed before 2012	(7)
Less: ST or *ST companies between 2012 and 2017	(24)
Final sample	279

Table 2 Distribution of the sample companies' industry

Industry	Code	Quantity	Percentage (%)
Manufacturing	*C13-C41*	250	89.61
Electricity, Heat, Gas and Water Production and Supply	*D44-D46*	29	10.39
Total	-	279	100

Table 3 "The carbon risk management index" scale

Item description	Key words	References
The establishment of a management organization or organization that undertakes carbon emission reduction duties.	Carbon, CO2, environment, environmental protection, emission reduction, value chain, industrial chain, green, ecological, climate change, sustainable, clean, target, ISO14001, management, management, strategy, economy, risk, internal control, awareness, monitoring, monitoring, energy saving	(Haque, 2017), (Mao *et al.*, 2017), 2017 CDP Climate Change Questionnaire Carbon Performance Item, CC1.1,CC2.2,CC3.1, CC3.2,CC3.3,CC5.1, CC6.1 etc.
The company has established a low carbon management charter or document to guide carbon emission reduction work.		
The company has developed more effective (executing or completed) emission reduction targets during the reporting year.		
The current corporate strategy and development policy of the company incorporates carbon reduction awareness.		
The company regularly monitors the carbon reduction process through an integrated management assessment system or a specific carbon management assessment system.		
The company has a complete monitoring and measurement system for carbon emissions (Scope 1, 2 & 3).		
The company adopted a market mechanism to save carbon during the reporting period (carbon emissions trading).		
During the reporting period, the company adopted clean energy/recycling technology for production as much as possible.		
The company disclosed the specific values of carbon emissions, emission reductions or emission reduction rates.		
The company completed its carbon reduction targets (carbon intensity and/or absolute carbon emission reductions) during the reporting period.		
Compared with the previous period, the company's emission reduction actions have achieved good results in terms of absolute carbon emission reduction and/or carbon intensity in this period.		
Enterprises receive social or government recognition through emission reduction management and emission reduction targets.		

Table 4 Definitions and measurements of variables

Variable type	Variables	Symbols	Measuring methods
Explained variable	Competitive Advantages	ΔROA_t	$\Delta ROA_t = ROA_t - ROA_{Ind\_average}$
Explanatory variable	Carbon Risk Management	CRC_{t-1}	According to Table 3
	Administrative Hierarchical Distance	*Gov-dis*	According to **3.2.2**
Control variable	Firm Size	*Size*	*Ln* (Total assets)
	Financial Leverage	*Lev*	Total liabilities / total assets
	Ownership	*Own*	If the company is a state-owned enterprise, *Own*=1, else *Own*=0.
	Firm Age	*Age*	*Ln* (Year being observed-Year of business registration +1)
	Organizational Slack	*Slack*	*Ln* (Current assets/Current liabilities)
	Ratio of Independent Directors	*BI*	Number of independent directors/Total number of directors
	Region	*Reg*	Dummy variable. If the company is in the east of China, *Reg*=1; else, *Reg*=0.
	Capital-intensity	*Cap*	Fixed assets/ total assets
	Industry	*Industry*	Control the impact of industry factors, set several industry dummy variables
	Year	*Year*	Control the impact of annual factors, set five dummy variables

Table 5 Descriptive statistics of variables

Variables	Observations	Mean	S.D.	Min	P=25%	Median	P=75%	Max
ΔROA_t	1395	-0.000	0.042	-0.115	-0.024	-0.005	0.020	0.141
CRC_{t-1}	1395	4.135	1.941	0.000	3.000	4.000	5.000	10.000
Gov-dis	1395	2.864	1.656	1.000	1.000	3.000	5.000	5.000
Lev	1395	0.464	0.192	0.008	0.320	0.475	0.617	1.037
Size	1395	10.010	0.590	8.767	9.573	9.943	10.350	11.860
Own	1395	0.599	0.490	0.000	0.000	1.000	1.000	1.000
Age	1395	2.886	0.286	1.792	2.773	2.890	3.091	3.638
Slack	1395	0.398	0.750	-2.037	0.005	0.317	0.774	4.651
BI	1395	0.189	0.060	0.000	0.156	0.185	0.222	0.471
Reg	1395	0.627	0.484	0.000	0.000	1.000	1.000	1.000
Cap	1395	0.335	0.196	0.009	0.179	0.292	0.463	0.970

Table 6 Correlation analysis among variables

	ΔROAt	*CRCt-1*	*Gov-dis*	*Lev*	*Size*	*Own*	*Industry*	*Age*	*Slack*	*BI*	*Reg*	*Cap*
ΔROAt	1.000	-0.038	-0.128***	-0.332***	-0.001	-0.120***	0.010	-0.096***	0.289***	0.070**	0.108***	-0.164***
CRCt-1	-0.045*	1.000	0.123***	0.210***	0.224***	0.1290***	-0.025	0.037	-0.220***	-0.103***	0.079**	0.160***
Gov-dis	-0.128***	0.141***	1.000	0.289***	0.226***	0.866***	0.182***	0.146***	-0.242***	-0.194***	-0.126***	0.118***
Lev	-0.329***	0.211***	0.286***	1.000	0.575***	0.284***	0.242***	0.206***	-0.790***	-0.163***	-0.092***	0.184***
Size	0.011	0.2510***	0.246***	0.568***	1.000	0.273***	0.159***	0.277***	-0.464***	-0.209***	-0.003	0.083***
Own	-0.120***	0.144***	0.889***	0.278***	0.283***	1.000	0.160***	0.205***	-0.248***	-0.194***	-0.132***	0.105***
Industry	0.002	0.006	0.188***	0.273***	0.196***	0.161***	1.000	0.015	-0.143***	0.011	0.0664**	-0.116***
Age	-0.137***	0.047*	0.159***	0.226***	0.227***	0.199***	-0.029	1.000	-0.238***	-0.043	-0.036	0.108***
Slack	0.255***	-0.214***	-0.251***	-0.781***	-0.478***	-0.241***	-0.177***	-0.247***	1.000	0.111***	0.072***	-0.519***
BI	0.037	-0.114***	-0.194***	-0.178***	-0.245***	-0.190***	-0.037	-0.050*	0.114***	1.000	-0.012	-0.004
Reg	0.112***	0.076***	-0.132***	-0.097***	0.020	-0.132***	0.066**	-0.041	0.065**	-0.014	1.000	-0.046**
Cap	-0.161***	0.176***	0.176***	0.235***	0.151***	0.145***	-0.065**	0.139***	-0.561***	0.003	-0.062**	1.000

Note.1. The Pearson correlation coefficient lies below the diagonal, and the Spearman correlation coefficient lies above it. 2. This table omits the t statistic of each coefficient; the values of ***, **, * expressed at 1%, 5% and the level of 10% are significant.

Table 7 Main effect regression analysis results (1)

Variables	(1) Full sample	(2) Subsample of strong product competition	(3) Subsample of weak product competition
CRCt-1	-0.000	-0.001	-0.000
	(-0.70)	(-1.12)	(-0.19)
Lev	-0.137***	-0.11***	-0.131***
	(-13.24)	(-5.90)	(-10.54)
Size	0.025***	0.035***	0.017***
	(11.10)	(8.49)	(6.53)
Own	-0.007***	0.005	-0.009***
	(-3.10)	(1.06)	(-3.03)
Age	-0.005	-0.014**	-0.002
	(-1.34)	(-2.03)	(-0.45)
Slack	-0.004	0.004	-0.011***
	(-1.54)	(0.95)	(-2.89)
Bi	0.015	0.076**	-0.018
	(0.82)	(2.39)	(-0.89)
Regi	0.004*	0.009**	0.001
	(1.81)	(2.43)	(0.44)
Cap	-0.059***	-0.051***	-0.056***
	(-7.21)	(-4.05)	(-5.37)
Constant	-0.155***	-0.262***	-0.073***
	(-6.21)	(-5.86)	(-2.60)
Year	Yes	Yes	Yes
Industry	Yes	Yes	Yes
N	1,395	562	833
Adj.R2	0.229	0.327	0.233
F	12.490	8.163	8.022

Note. T statistics are shown in brackets; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 8 Main effect regression analysis results (2)

Variables	(1) Full sample	(2) Subsample of strong product competition	(3) Subsample of weak product competition
CRC_{t-1}	0.003*	0.002	0.003*
	(1.83)	(0.49)	(1.71)
CRC_{t-1}^2	-0.000**	-0.000	-0.000*
	(-2.45)	(-0.66)	(-1.73)
Lev	-0.131***	-0.104***	-0.126***
	(-12.61)	(-3.95)	(-10.13)
Size	0.024***	0.033***	0.016***
	(10.50)	(8.06)	(6.20)
Own	-0.007***	0.006	-0.008***
	(-2.76)	(1.54)	(-2.85)
Age	-0.010**	-0.021***	-0.005
	(-2.74)	(-3.31)	(-1.10)
Slack	0.004	0.005	-0.011***
	(1.23)	(1.13)	(-2.65)
Bi	0.016	0.084***	-0.020
	(0.88)	(2.63)	(-0.98)
Regi	0.004**	0.009**	0.002
	(1.87)	(2.34)	(0.57)
Cap	-0.055***	-0.047***	-0.053***
	(6.71)	(-3.71)	(-5.07)
Constant	-0.145***	-0.249***	-0.071***
	(-5.73)	(-5.49)	(-2.61)
Year	Yes	Yes	Yes
Industry	Yes	Yes	Yes
N	1,395	562	833
$Adj.R^2$	0.234	0.354	0.223
F	12.530	8.250	8.220

Note. T statistics are shown in brackets; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 9 Moderating effect regression analysis results

Variables	(1) Full sample	(2) Subsample of strong product competition	(3) Subsample of weak product competition
CRC_{t-1}	0.012**	0.009	0.009*
	(2.36)	(1.27)	(1.75)
CRC_{t-1}^2	-0.001***	-0.001	-0.001**
	(-2.78)	(-1.24)	(-2.20)
Gov-dis	0.005	0.011	-0.001
	(1.63)	(2.38)	(-0.24)
Gov-dis × CRC_{t-1}	-0.003**	-0.004*	-0.002*
	(-2.10)	(-1.69)	(-1.69)
Gov-dis × CRC_{t-1}^2	0.000**	0.000	0.000*
	(2.51)	(1.43)	(1.96)
Lev	-0.14***	-0.110***	-0.132***
	(-13.39)	(-5.88)	(-10.58)
Size	0.025***	0.035***	0.017***
	(11.14)	(8.59)	(5.15)
Own	-0.009**	-0.004	-0.001
	(-1.89)	(-0.57)	(-0.81)
Age	-0.005	-0.014**	-0.003
	(-1.37)	(-2.15)	(-0.24)
Slack	-0.005*	0.004	-0.012***
	(-1.69)	(0.79)	(-2.91)
Bi	0.0164	0.082***	-0.017
	(0.92)	(2.57)	(-0.84)
Regi	0.004*	0.009**	0.001
	(1.75)	(2.34)	(0.28)
Cap	-0.061***	-0.154***	0.056***
	(14.71)	(-4.19)	(11.23)
Constant	-0.172***	-0.287***	-0.080***
	(-6.50)	(-6.22)	(-5.32)
Year	Yes	Yes	Yes
Industry	Yes	Yes	Yes
N	1,395	562	833
Adj.R^2	0.275	0.329	0.238
F	11.66	7.56	7.49

Note. T statistics are shown in brackets; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 10 Test results of endogenous control

Variables	Main effect			Moderating effect		
	(1)	(2)	(3)	(4)	(5)	(6)
CRC_{t-1}	0.001*	0.000	0.002*	0.004**	0.003	0.005*
	(1.75)	(0.08)	(1.78)	(2.11)	(0.710)	(1.97)
CRC_{t-1}^2	-0.000**	-0.000	-0.000*	-0.001**	-0.000	-0.001**
	(-2.25)	(-0.05)	(-1.85)	(-2.52)	(-0.59)	(-2.42)
Gov-dis				0.002	0.006*	0.001
				(1.26)	(1.80)	(0.47)
Gov-dis × CRC_{t-1}				-0.001**	-0.002	-0.001*
				(-2.65)	(-1.25)	(-1.83)
Gov-dis × CRC_{t-1}^2				0.000**	0.000	0.000*
				(2.17)	(1.08)	(1.78)
ΔROA_{t-1}	0.586***	0.708***	0.385***	0.585***	0.708***	0.382***
	(28.32)	(24.64)	(12.70)	(28.21)	(24.68)	(12.54)
Lev	-0.061***	-0.042***	-0.082***	-0.066***	-0.045***	-0.087***
	(-7.16)	(-3.24)	(-6.91)	(-7.66)	(-3.51)	(-7.30)
Size	0.008***	0.005*	0.009***	0.009***	0.007**	0.009***
	(4.36)	(1.78)	(3.67)	(4.75)	(2.17)	(3.88)
Own	-0.001	0.006*	-0.004	-0.004	0.000	-0.000
	(-0.61)	(1.92)	(-1.50)	(-0.96)	(0.01)	(-0.01)
Age	-0.001	-0.003	-0.001	0.001	-0.001	0.000
	(-0.44)	(-0.62)	(-0.21)	(0.23)	(-0.18)	(0.04)
Slack	-0.002	0.000	-0.007**	-0.003	-0.001	-0.008**
	(-0.96)	(0.00)	(-2.00)	(-1.36)	(-0.23)	(-2.28)
Bi	-0.004	0.022	-0.019	0.002	0.027	-0.014
	(-0.25)	(0.99)	(-1.05)	(0.15)	(1.25)	(-0.77)
Regi	0.003	0.003	0.002	0.002	0.004	0.001
	(1.45)	(1.30)	(0.66)	(1.37)	(1.37)	(0.37)
Cap	-0.021***	-0.005	-0.036***	-0.024***	-0.008	-0.038***
	(-3.15)	(-0.61)	(-3.69)	(-3.65)	(-0.93)	(-3.93)
Constant	-0.049**	-0.042**	-0.036***	-0.058***	-0.056**	-0.038***
	(-2.40)	(-2.05)	(-2.70)	(-2.70)	(-2.51)	(-2.35)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
N	1,395	562	833	1,395	562	833
$Adj.R^2$	0.519	0.680	0.353	0.529	0.691	0.363
F	40.510	34.130	14.320	35.800	30.210	12.580

Note. T statistics are shown in brackets; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 11 Robustness test results (1)

	Main effect			Moderating effect		
Variables	(1)	(2)	(3)	(1)	(2)	(3)
CRCt-1	0.008***	0.003	0.016***	0.012***	0.006	0.012*
	(3.57)	(1.36)	(4.54)	(2.80)	(1.09)	(1.76)
CRCt-1²	-0.001***	-0.000	-0.002***	-0.002***	-0.001	-0.001**
	(-3.24)	(-1.00)	(-4.30)	(-2.82)	(-1.13)	(-2.43)
Gov-dis				0.002	-0.001	0.001
				(0.92)	(-0.44)	(0.14)
Gov-dis × *CRCt-1*				-0.002**	-0.001	-0.001**
				(-1.97)	(-0.50)	(-1.98)
Gov-dis × *CRCt-1²*				0.000**	0.000	0.000*
				(2.47)	(0.73)	(1.85)
Lev	-0.140***	-0.132***	-0.119***	-0.139***	-0.131***	-0.118***
	(-13.54)	(-10.61)	(-6.54)	(-13.50)	(-10.49)	(-6.48)
Size	0.025***	0.016***	0.033***	0.025***	0.016***	0.034***
	(10.66)	(6.09)	(8.26)	(10.62)	(5.91)	(8.24)
Own	-0.007***	-0.009***	0.008*	-0.010**	-0.004	-0.002
	(-2.97)	(-3.06)	(1.86)	(-2.03)	(-0.62)	(-0.28)
Age	-0.006	-0.002	-0.013**	-0.006	-0.003	-0.013**
	(-1.42)	(-0.55)	(-2.01)	(-1.46)	(-0.63)	(-1.99)
Slack	-0.005*	-0.012***	0.002	-0.005*	-0.012***	0.003
	(-1.66)	(-2.95)	(0.58)	(-1.68)	(-2.95)	(0.65)
Bi	0.017	-0.016	0.076**	0.017	-0.018	0.080**
	(0.98)	(-0.81)	(2.45)	(0.95)	(-0.90)	(2.55)
Regi	0.003	0.001	0.007*	0.003	0.001	0.007*
	(1.47)	(0.33)	(1.83)	(1.38)	(0.21)	(1.87)
Cap	-0.058***	-0.056***	-0.051***	-0.060***	-0.056***	-0.053***
	(-7.19)	(-5.40)	(-4.16)	(-7.27)	(-5.28)	(-4.20)
Constant	-0.161***	-0.070**	-0.275***	-0.166***	-0.066**	-0.276***
	(-6.35)	(-2.42)	(-6.24)	(-6.28)	(-2.18)	(-6.07)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
N	1,395	562	833	1,395	562	833
Adj.R2	0.255	0.349	0.235	0.255	0.347	0.234
F	12.650	7.898	8.727	11.860	7.347	8.111

Note. T statistics are shown in brackets; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 12 Robustness test results (2)

Variables	Main effect			Moderating effect		
	(1)	(2)	(3)	(4)	(5)	(6)
CRC_{t-1}	0.003*	0.002	0.004*	0.011**	0.008	0.010*
	(1.78)	(0.51)	(1.79)	(2.30)	(1.08)	(1.68)
CRC_{t-1}^2	-0.000*	-0.000	-0.000*	-0.001***	-0.001	-0.001**
	(-1.87)	(-0.64)	(-1.77)	(-2.71)	(-1.08)	(-2.13)
Gov-dis				0.005	0.011**	-0.001
				(1.59)	(2.15)	(-0.21)
Gov-dis × CRC_{t-1}				-0.003**	-0.003	-0.002*
				(-1.96)	(-1.41)	(-1.85)
Gov-dis × CRC_{t-1}^2				0.000**	0.000	0.000*
				(2.39)	(1.22)	(1.76)
Lev	-0.136***	-0.103***	-0.131***	-0.144***	-0.108***	-0.137***
	(-12.10)	(-5.15)	(-9.72)	(-12.84)	(-5.45)	(-10.16)
Size	0.025***	0.034***	0.017***	0.027***	0.036***	0.018***
	(10.21)	(7.78)	(6.22)	(10.80)	(8.27)	(6.44)
Own	-0.007***	0.007	-0.008***	-0.010*	-0.005	-0.002
	(-2.64)	(1.47)	(-2.65)	(-1.94)	(-0.59)	(-0.290)
Age	-0.011***	-0.023***	-0.005	-0.006	-0.016**	-0.003
	(-2.66)	(-3.45)	(-1.06)	(-1.42)	(-2.31)	(-0.62)
Slack	-0.003	0.006	-0.010**	-0.005	0.004	-0.012***
	(-1.11)	(1.23)	(-2.42)	(-1.56)	(0.93)	(-2.67)
Bi	0.019	0.085**	-0.013	0.020	0.083**	-0.010
	(0.99)	(2.49)	(-0.62)	(1.06)	(2.44)	(-0.46)
Regi	0.004*	0.009**	0.002	0.004	0.009**	0.001
	(1.75)	(2.23)	(0.68)	(1.63)	(2.23)	(0.39)
Cap	-0.058***	-0.048***	-0.056***	-0.064***	-0.056***	-0.059***
	(-6.57)	(-3.58)	(-4.90)	(-7.20)	(-4.08)	(-5.15)
Constant	-0.091***	-0.189***	-0.020**	-0.118***	-0.225***	-0.029**
	(-3.32)	(-3.92)	(-2.08)	(-4.10)	(-4.59)	(-2.57)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
N	1,395	562	833	1,395	562	833
$Adj.R^2$	0.375	0.377	0.280	0.388	0.391	0.293
F	23.570	10.710	10.800	21.060	9.575	9.639

Note. T statistics are shown in brackets; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 13 Robustness test results (3)

Variables	Main effect			Moderating effect		
	(1)	(2)	(3)	(4)	(5)	(6)
CRC_{t-1}	0.004*	0.006	0.004*	0.011**	0.0090	0.011*
	(1.80)	(1.41)	(1.73)	(2.50)	(1.3200)	(1.96)
CRC_{t-1}^2	-0.000*	-0.001	-0.000*	-0.002***	-0.0010	-0.002**
	(-1.95)	(-1.57)	(-1.73)	(-3.09)	(-1.4100)	(-2.55)
Gov-dis				0.003	0.0070	-0.001
				(0.96)	(1.3700)	(-0.30)
Gov-dis × CRC_{t-1}				-0.002*	-0.0020	-0.002*
				(-1.78)	(-0.9500)	(-1.80)
Gov-dis × CRC_{t-1}^2				0.000**	0.0000	0.000*
				(2.41)	(0.8000)	(1.92)
Lev	-0.133***	-0.117***	-0.125***	-0.144***	-0.1260***	-0.133***
	(-11.36)	(-5.08)	(-9.21)	(-12.22)	(-5.4600)	(-9.71)
Size	0.026***	0.033***	0.019***	0.028***	0.0350***	0.020***
	(10.38)	(6.76)	(6.83)	(11.04)	(7.1800)	(7.16)
Own	-0.008***	0.007	-0.010***	-0.009*	-0.0010	-0.003
	(-3.26)	(1.45)	(-3.15)	(-1.75)	(-0.1000)	(-0.43)
Age	-0.008*	-0.022***	-0.001	-0.002	-0.0140**	0.001
	(-1.88)	(-3.24)	(-0.24)	(-0.51)	(-2.0300)	(0.21)
Slack	-0.003	0.002	-0.010**	-0.004	0.0000	-0.011**
	(-0.84)	(0.39)	(-2.18)	(-1.37)	(0.0200)	(-2.39)
Bi	0.006	0.061*	-0.026	0.006	0.0580	-0.024
	(0.31)	(1.73)	(-1.27)	(0.33)	(1.6100)	(-1.14)
Regi	0.006***	0.013***	0.003	0.006**	0.0120***	0.003
	(2.58)	(3.02)	(1.29)	(2.42)	(2.92000)	(0.93)
Cap	-0.071***	-0.080***	-0.055***	-0.079***	-0.085***	-0.060***
	(-7.80)	(-5.23)	(-4.85)	(-8.58)	(-5.5400)	(-5.26)
Constant	-0.171***	-0.228***	-0.111***	-0.199***	-0.2630***	-0.124***
	(-6.10)	(-4.38)	(-3.58)	(-6.79)	(-4.9000)	(-3.76)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
N	1,250	490	760	1,250	490	760
$Adj.R^2$	0.257	0.329	0.235	0.277	0.345	0.256
F	13.680	8.261	8.519	12.680	7.432	7.860

Note. T statistics are shown in brackets; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 14 Robustness test results (4)

Variables	Main effect			Moderating effect		
	(1)	(2)	(3)	(4)	(5)	(6)
CRCt-1	0.003**	0.002	0.004*	0.010**	0.008	0.010*
	(2.34)	(0.55)	(1.73)	(2.320)	(1.18)	(1.82)
CRCt-1²	-0.000*	-0.000	-0.000*	-0.001***	-0.001	-0.001**
	(-1.78)	(-0.69)	(-1.66)	(-2.74)	(-1.23)	(-2.240)
Gov-dis				0.004	0.010**	-0.001
				(1.59)	(2.11)	(-0.17)
Gov-dis × *CRCt-1*				-0.003**	-0.003	-0.002*
				(-2.06)	(-1.61)	(-1.76)
Gov-dis × *CRCt-1²*				0.000**	0.000	0.000*
				(2.47)	(1.44)	(1.70)
Lev	-0.133***	-0.113***	-0.125***	-0.140***	-0.117***	-0.132***
	(-12.78)	(-5.97)	(-10.11)	(-13.59)	(-6.28)	(-10.59)
Size	0.023***	0.030***	0.016***	0.025***	0.033***	0.017***
	(10.24)	(7.28)	(6.34)	(11.08)	(8.08)	(6.62)
Own	-0.008***	0.002	-0.008***	-0.010**	-0.006	-0.002
	(-3.18)	(0.44)	(-2.87)	(-2.01)	(-0.79)	(-0.28)
Slack	-0.003	0.004	-0.010***	-0.005*	0.003	-0.011***
	(-1.07)	(0.99)	(-2.59)	(-1.65)	(0.59)	(-2.90)
Regi	0.004*	0.009**	0.002	0.004*	0.009**	0.001
	(1.91)	(2.21)	(0.60)	(1.74)	(2.22)	(0.30)
Cap	-0.055***	-0.043***	-0.054***	-0.061***	-0.053***	-0.057***
	(-6.70)	(-3.40)	(-5.19)	(-7.40)	(-4.08)	(-5.44)
Constant	-0.163***	-0.257***	-0.091***	-0.178***	-0.280***	-0.094***
	(-7.19)	(-6.12)	(-3.59)	(-7.53)	(-6.60)	(-3.50)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
N	1,395	562	833	1,395	562	833
Adj.R2	0.231	0.290	0.222	0.251	0.318	0.239
F	12.960	7.954	8.675	12.150	7.530	7.860

Note. T statistics are shown in brackets; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

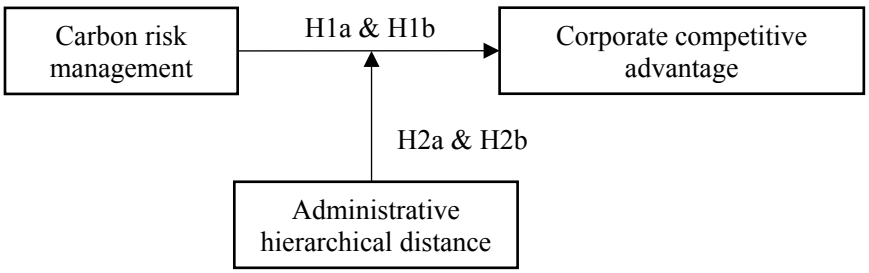

Fig.1 Theoretical model

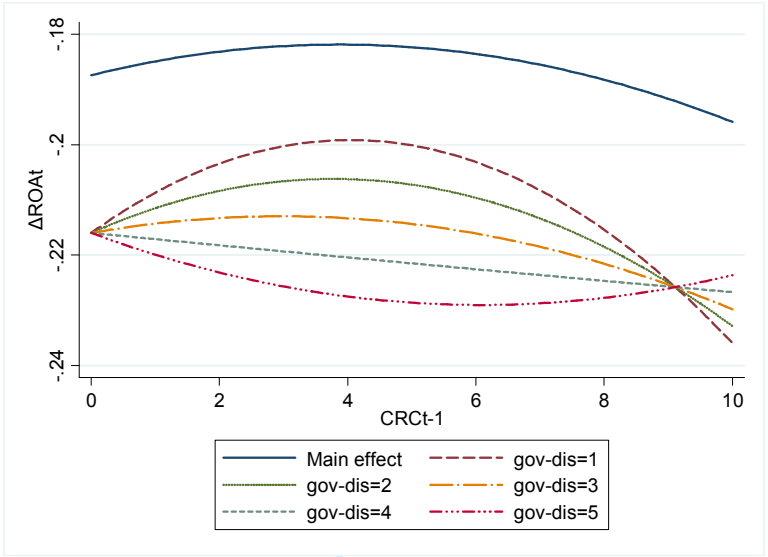

Fig. 2 Relation between carbon risk management and advantages competition

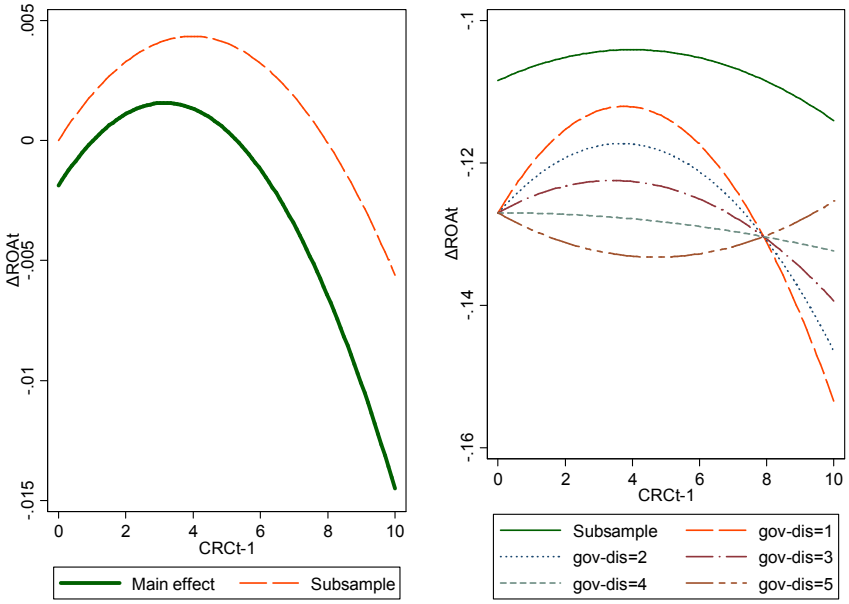

Fig.3 Group test based on product competition