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Network attention and carbon dioxide emission performance of agricultural enterprises: Empirical evidence from China's baidu search index

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Based on the network attention data of China's agricultural listed companies from 2012 to 2020, this paper uses the IV model to measure and investigate the impact of network attention on the carbon dioxide emission performance of China's agricultural listed companies and its mechanism. The findings are as follows: 1) The carbon dioxide emission intensity of listed agricultural companies in China is generally decreasing year by year and the carbon dioxide emission performance is improving; 2) The increasing network attention has significantly reduced the carbon dioxide emission intensity of agricultural listed companies and brought about better carbon dioxide emission performance; 3) The relationship between network attention and carbon dioxide emission performance of agricultural listed companies has network, regional and property heterogeneity; 4) The investment in environmental protection has strengthened the inhibition effect of network attention on the unit carbon dioxide emissions of agricultural listed companies. The research conclusion enriches the literature on "network concern – environmental governance", and also provides ideas for developing countries to exert the environmental governance effect of network concern in the process of carbon neutrality.

1 Introduction

China is a large agricultural country and the largest carbon dioxide (CO2) emitter in the world. In the process of agricultural modernization, the agricultural sector is an important source of carbon dioxide emissions in China. According to the statistics of the Food and Agriculture Organization of the United Nations (FAO), China's agricultural sector's generalized carbon dioxide emissions reached 663 million tons in 2019, accounting for 11.1% of the global agricultural sector's total emissions. The Chinese government attaches great importance to how to reduce the intensity of carbon dioxide emissions from agricultural enterprises and achieve the goal of carbon neutrality. In recent years, the Chinese central government has continuously strengthened the construction of ecological civilization, actively promoted carbon neutrality in various fields, including the agricultural sector, and released a strong signal of concern about environmental protection, resource recycling, carbon reduction, and carbon reduction (Hansen et al., 2018). In 2015, China

adopted the new Environment Protection Law. In 2021, the work report of the central government made clear for the first time the overall goal of carbon emission reduction of carbon peak in 2030 and carbon neutrality in 2060. The above has greatly enhanced the binding force of formal environmental regulations on environmental pollution behavior, and the cost of agricultural enterprises for pollution control and operation has also increased (Yu and Morotomi, 2022). Moreover, in addition to the formal environmental regulations implemented by the government, the public's attention to the network should not be underestimated. Under the background that environmental protection is increasingly valued by society, Chinese people have been paying close attention to the environmental pollution problem of agricultural enterprises, and have made a voice in the network to form a strong network attention, to provide support for the green development of agricultural enterprises. However, as an informal environmental regulation that complements formal environmental regulation, whether and how network attention affects the carbon dioxide emission performance of agricultural enterprises has not received enough attention from the academic community (Chen and Wu, 2021). In particular, there remain some academic differences in the relationship between network attention and the performance of companies' carbon dioxide emissions. The "irrelevance theory" (Hart and Ahuja, 1996; Ziegler et al., 2008), "promotion theory" (Kathuria, 2007; Zheng et al., 2018; Han, 2022), and other views have been put forward. The lack of direct empirical evidence makes it necessary to systematically investigate and analyze the impact and mechanism of network attention on the carbon dioxide emission performance of agricultural listed companies under the Chinese scenario. Given this, this paper takes China's agricultural listed companies from 2012 to 2020 as a sample to systematically investigate the possible impact of network attention on carbon dioxide emission performance and its impact mechanism.

Compared with the previous literature, the marginal contributions that this study may bring are as follows: First, because of the controversy of "network attention and carbon dioxide emission performance", we use the data generated by the largest search engine in China to systematically investigate the impact of network attention on carbon dioxide emission performance; Second, focus on the agricultural sector, which has been less involved in previous studies, analyze and examine the impact mechanism of network attention on the carbon dioxide emission performance of agricultural listed companies, and thicken the mechanism literature of "network attention - environmental governance" in developing countries; Third, the conclusions of this paper also provide ideas and suggestions for promoting the green development of agriculture in developing countries and strengthening the carbon neutral governance under the network media.

2 Literature review

Carbon dioxide emission performance is a beneficial result of the ecological restoration and protection of environmental pollution by the emission subject (Hou et al., 2021), which shows the positive action on the prevention and control of greenhouse gases such as carbon dioxide (Nkhata and Breen, 2010). It is worth noting that

existing studies have shown that network attention as a non-environmental regulation can bring direct and indirect effects on the performance of carbon dioxide emissions (Sissenwine, 2007). Focusing on the issue of network attention and carbon dioxide emission performance, existing studies have focused on the impact of formal environmental regulations on carbon dioxide emission performance, and the impact and mechanism of network attention on carbon dioxide emission performance.

The first piece of literature is about the relationship between formal environmental regulation and carbon dioxide emission performance. Most of the existing studies believe that formal environmental regulations such as environmental protection laws can help promote carbon dioxide emission performance. On the one hand, the traditional hypothesis is that there is a mutual constraint between the environmental objectives and the objectives of the enterprise. Meeting the objectives of one party will inevitably negatively affect the objectives of the other party, which could have a negative impact on the performance of carbon dioxide emissions (Johnson, 2010). For example, Gray and Shadbegian (1995) took the U.S. pulp and paper industry, petroleum refining industry, and steel industry as the research object, and found that the increase of environmental costs inhibited the growth of productivity level, that is, the productivity level and growth rate of enterprises subject to stricter environmental control were significantly lower than those subject to less environmental control. Yang et al. (2012) also show that it is difficult to improve the performance of companies' carbon dioxide emissions solely through spontaneous market behaviour. Cui et al. (2015) analyzed the carbon dioxide emissions performance of the U.S. manufacturing industry and found that there was an inverse relationship between enterprise productivity and carbon dioxide emissions per unit output. On the other hand, in recent years, more and more scholars believe that formal environmental regulation led by the government can significantly improve the performance of carbon dioxide emissions (Shen, 2016). Zhao and Luo (2017) have shown that official regulations, including emissions monitoring and the implementation of standards, are key factors in promoting the reduction of carbon dioxide emissions. Wang et al. (2020) found that formal environmental regulations such as environmental supervision have a positive effect on the reduction of carbon dioxide emissions in Chinese provinces. Jia and Lin (2021) proposed that under China's "carbon neutral" policy scenario, formal environmental regulations should play a moderating role in reducing the intensity of carbon dioxide emissions.

The second literature on the relationship between network attention and the performance of carbon dioxide emissions, but there are also a few arguments. First, a small number of studies have found that informal environmental regulation such as network attention, has no correlation with carbon dioxide emission performance. Hart and Ahuja (1996) found that environmental protection measures taken by non-governmental organizations or markets do not clearly correlate with the performance of carbon dioxide emissions. Ziegler et al. (2008) found that informal environmental regulation could not achieve an obvious response to environmental governance. Second, informal environmental regulations such as media pressure and network pressure can significantly improve the performance of carbon dioxide emissions. Kathuria (2007) found that the pressure of news

reports significantly reduced the pollutant emission intensity of enterprises according to the research on media pressure and environmental governance performance in India. Zheng et al. (2018) found that online media attention will put greater pressure on companies' environmental governance, forcing them to respond to improve the performance of carbon dioxide emissions. Han (2022) proposed that the pressure from the media and public opinion supervision becomes the power of enterprise environmental protection, which can imperceptibly change the enterprise's environmental protection ideas, from environmental end treatment to cleaner production, and bring a positive impact on enterprise environmental governance.

The third literature discusses the mechanism of the influence of network attention on carbon dioxide reduction. Most scholars focus on the pressure mechanism, which can be subdivided into reputation pressure, disciplinary pressure, and market pressure. First of all, network attention will bring reputation pressure to pollution-discharging enterprises, and affect carbon dioxide emissions and governance behavior. Lesser (2008) pointed out that network attention would bring reputation pressure to enterprises, forcing enterprises to make decisions to fulfill environmental protection responsibilities and improve environmental performance. Khaqqi et al. (2018) believed that for the consideration of future development and enterprise value, enterprises often attach importance to their reputation in the network. The media pays attention to environmental protection issues such as carbon dioxide emissions of enterprises, puts them under reputation pressure, and promotes enterprises to increase investment in environmental protection and improve environmental performance. Moreover, higher network attention will attract the attention of regulatory authorities, especially the unofficial negative environmental protection information disclosed by the network, which is easy to bring administrative punishment pressure and risk to enterprises and urge them to improve their carbon dioxide emission behavior. Cheng and Liu (2018) found that network information would increase regulatory attention and the likelihood of penalties for heavily polluting corporations. Zhang and Xie (2020) found that the supply of public opinion and other information increases the cost of pollution and the fear of environmental punishment, which helps to form external constraints on environmental pollution behavior. In addition, media and network attention have brought market pressure to enterprises and promoted enterprises to reduce carbon emissions. For example, Cai et al. (2020) believed that media and network attention would bring strong market pressure to listed companies in the capital market and stimulate listed companies to adopt green technology to reduce environmental risks. Lei et al. (2022) pointed out that under the network focus scenario, listed companies have the motivation to respond to market green development expectations and improve environmental competitiveness.

To sum up, although many pieces of literature believe that enterprises will improve the performance of carbon dioxide emissions due to the pressure of network attention, there are still some conclusions to the contrary. In particular, the existing literature has not explored the relationship between the agricultural sector's network concern and carbon dioxide emissions performance, and there is little direct evidence from the agricultural sector in developing countries, which requires

systematic analysis and investigation. Accordingly, this paper focuses on the impact of the network attention of agricultural listed companies, the main body of pollutant emissions in non-industrial sectors ignored by the academic community, on the performance of carbon dioxide emissions, to strengthen the academic understanding of "the mystery of network attention and agricultural carbon reduction".

3 Measurement models and data

3.1 Instrumental variable model (IV model)

The instrumental variable model is an effective estimation model to solve the endogenous problem, and it has strong applicability to alleviate the self-selection of samples and overcome the high correlation between independent variables and random disturbance items (Amemiya, 1985). Compared with other estimation models, the instrumental variable model makes the causal relationship evaluation between independent variables and dependent variables more objective by looking for instrumental variables that are highly related to independent variables and not related to random error terms (Cragg and Donald, 1993). formula (1) shows the IV model:

$$
\begin{aligned}
y_{i,t} &= \beta_0 + \beta_1 x_{i,t} + u_{i,t} \\
Cov(Z_{i,t}, u_{i,t}) &= 0 \\
Cov(Z_{i,t}, x_{i,t}) &\neq 0 \\
y_{i,t} &= \beta_0 + \beta_1 z_{i,t} + u_{i,t}
\end{aligned} \tag{1}
$$

In Eq. 1, $y_{i,t}$, $x_{i,t}$, $z_{i,t}$ uit respectively represent dependent variable, independent variable, instrumental variable, and random disturbance term. Cov represents the covariance between variables. β_0, β_1 represent the estimated coefficient. In the original estimation model, there is often a high correlation between the independent variable $x_{i,t}$ and the random disturbance term $u_{i,t}$, resulting in biased estimation. The endogenous problem of the original model can be effectively solved by introducing the tool variable z_{it} instead of the independent variable $x_{i,t}$.

The IV model is the basis for us to examine the relationship between network attention and the carbon dioxide emission performance of agricultural enterprises. Next, based on Eq. 1, the exogenous instrumental variable model is used to examine the impact of network attention on the carbon dioxide emission performance of agricultural enterprises. At the same time, it is effective to use lag-independent variables to construct tool variables, which is helpful to estimate consistent estimators of parameters (Koop et al., 2012). The specific model 2) is constructed, as shown in Eq. 2:

$$
Emp\_intensity_{i,t} = \beta_0 + \beta_1 Media_{i,t-1} + \beta_2 Cotrollers_{i,t} + Year + \delta_{i,t} \tag{2}
$$

In Eq. 2, $Emp\_intensity$ represents the performance of carbon dioxide emissions, $Media$ refers to the instrumental variable of network attention in the lag period, including two specific instrumental variables, namely, the total amount of annual network attention ($Media\_total$), annual total urban broadband access users ($Access\_user$). Theoretically, these instrumental variables are highly correlated with network attention and have

exogenous characteristics. *Controllers* represent other control variables that may affect carbon dioxide emission performance, and *Year* represents the annual fixed effect. δ is a random disturbance term, i represents the individual of agricultural listed company, and t represents time.

3.2 Variables

3.2.1 Dependent variable

Carbon dioxide emission performance (*Emp_intensity*): Carbon dioxide emission performance reflects the main achievements of economic organizations in environmental protection, including whether they meet the environmental protection standards and the intensity of unit carbon dioxide emissions. However, for the agricultural listed companies studied in this paper, as the enterprises concerned with the public and the network, they have reached the basic environmental protection standards stipulated by the state, and it is difficult to fully reflect the environmental governance results by using relevant variables. Referring to the practice of Patten (2005), Zhang and Cao (2015), the six broad carbon dioxide (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) defined in the Kyoto Protocol is used as the statistical caliber, and the unit carbon dioxide emission intensity is used as the specific measurement index.

3.2.2 Independent variable

Tool variables of network attention (*Media*): Network attention refers to the degree of the public's attention to the enterprise based on the internet media, which is measured by the search index. In the context of the Chinese internet, the public first chooses Baidu Search, the largest local search engine, to focus on relevant enterprises and express their opinions online. With reference to the practice of McCreery (2010), based on the number of internet users searching in Baidu, define the first tool variable, the total annual network attention (*Media_total*). Furthermore, to avoid the error in the estimation of a single indicator, based on Kitty (2011) and other ideas, the second instrumental variable - the annual total number of urban broadband access users (*Access_user*) is set.

3.2.3 Control variables

Environmental protection administrative punishment (*Epap*): Formal environmental regulation is an important external factor driving enterprises to improve environmental protection behavior. A strong administrative sanction to protect the environment will limit companies' carbon emissions behaviour and correct their inappropriate behaviour in environmental governance. In order to control the impact of administrative power on the performance of carbon dioxide emissions, referring to the practice of Ding and Shahzad (2022), the intensity of formal environmental regulation is measured based on the annual environmental protection administrative punishment of agricultural listed companies.

Financial leverage (*Lev*): Since carbon reduction itself is a high investment, long cycle process, enterprises need to raise necessary funds for environmental protection equipment upgrading, emission reduction technology upgrading, etc. through financial leverage. The ratio of total liabilities to total assets of agricultural listed companies is used to measure the level of financial leverage.

Enterprise size (*Size*): In addition to the capital factor, another factor closely related to the performance of carbon dioxide emissions is enterprise size. Larger enterprises tend to emit more greenhouse gases, and the corresponding greenhouse gas emission intensity will also be affected. We refer to the practice of Shao et al. (2016) and introduce the enterprise scale variable. The logarithmic measurement of enterprise asset scale is intended to control the change of environmental protection governance effect brought by enterprise scale.

Development status (*Growth*): Enterprises at different stages of development will present different environmental governance motivations. When enterprises develop rapidly, their carbon dioxide emissions will increase. They will face greater pressure on environmental governance and may invest more funds in the field of environmental governance to promote the improvement of carbon dioxide emissions performance. We learn from Soltani et al. (2021). The growth rate of business income is used to measure the development status, so as to control the impact of development status on carbon dioxide emission performance.

Age of establishment (*Firmage*): The operation and management activities of enterprises that have been established for a long time are relatively standardized, and they are motivated to implement more strict environmental governance behaviors, thus causing changes in the performance of enterprises' carbon dioxide emissions. Refer to Cole et al. (2015) and measure the above indicators by taking logarithms of the company's establishment years.

Board governance (*Board*): The board of directors is the core organization for business decision-making, and the governance of the board of directors determines the corporate environmental governance behavior to a large extent. A larger board size means more directors participate in environmental governance decisions. In order to control the decision-making behavior of the board of directors on environmental governance, referring to the practice of Okoye (2010), we measure the governance variables of the board of directors by taking logarithms of the size of the board of directors.

3.2.4 Regulated variable

Environmental protection investment (*Epinvest*): Listed agricultural companies under the pressure of network media have the motivation to increase environmental protection investment and improve environmental performance. At a time when environmental protection is becoming increasingly important, network attention may stimulate enterprises to pay attention to environmental protection, force them to invest more funds in the field of environmental protection, and bring about changes in the carbon dioxide emission performance of agricultural listed companies. With reference to Liu et al. (2022), it is measured by the annual environmental protection investment of agricultural listed companies. Table 1.

3.3 Sample selection and data source

This paper selects China's A-share agricultural listed companies from 2012 to 2020 as the initial sample, and

TABLE 1 Variable definitions.

Variable		Variable symbol	Variable declaration
Dependent variable	Carbon dioxide emission performance	*Emp_intensity*	Broad carbon dioxide emissions of agricultural listed companies (tons)/operating income (100 million yuan)
Independent variable	Total annual network attention	*Media_total*	Annual Baidu search total index, taking logarithms
	Annual broadband access user	*Access_user*	Annual broadband user access users (thousands) in the city where the company is located, then logarithm
Control and regulation variables	Environmental protection administrative punishment	*Epap*	The administrative penalty for environmental protection in the current year is 1, otherwise 0
	Financial leverage	*Lev*	Total liabilities/assets
	Enterprise size	*Size*	Asset scale, then logarithm
	Development status	*Growth*	(Operating income of the current year - operating income of the previous year)/operating income of the previous year
	Age of establishment	*Firmage*	The number of years of establishment of the company, then logarithm
	Board governance	*Board*	Number of directors, logarithm
	Environmental protection investment	*Epinvest*	Annual environmental protection investment (ten thousand yuan), then logarithm
	Year	*Year*	Set the year dummy variable, 1 for the current year, 0 for other years

(source: China Finance and Economics database).

TABLE 2 Descriptive statistics of the main variables.

Variable	Sample size	Mean value	Standard deviation	Minimum	Maximum
Emp_intensity	324	3.552	11.853	0.000	116.755
Media_total	324	12.329	0.837	4.094	14.036
Access_user	324	7.276	0.774	4.593	9.126
Epap	324	0.006	0.078	0.000	1.000
Lev	324	0.443	0.213	0.050	1.249
Size	324	21.765	1.033	19.478	25.532
Growth	324	0.114	0.466	-0.751	4.383
Firmage	324	2.842	0.328	1.609	3.611
Board	324	2.103	0.228	1.609	2.773
Epinvest	324	15.545	1.527	7.507	18.848

(source: China Finance and Economics database).

standardizes the sample as follows: 1) exclude the sample of agricultural listed companies that are specially treated by the CSRC and have delisting risks; 2) Remove the samples of agricultural listed companies with more missing data; 3) Exclude the sample of agricultural listed companies that have been listed for less than 2 years. In addition, in order to supplement panel data, some missing values are supplemented by the industry average. After sorting out, 324 sample observations were obtained. The Baidu search index is derived from the data disclosed by the Baidu search engine, and other variable data is derived from the China Finance and Economics (CSMAR) database.

4 Data analysis and discussion

4.1 Descriptive statistics

Table 2 reports the descriptive statistics of the main variables. The mean value of *Emp_intensity* is 3.552, the standard deviation is 11.853, the minimum value is 0.000, and the maximum value is 116.755, which indicates that there are obvious differences in carbon dioxide emission intensity of Chinese agricultural listed companies. Combined with the time series distribution data in Table 3, from the data on carbon dioxide emission intensity of listed agricultural companies in China from 2012 to 2020, the

TABLE 3 Time series distribution of carbon dioxide emission performance (*Emp_intensity*) and network attention (*Media*).

Variable	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean
Emp_intensity	2.800	2.366	0.025	0.104	0.017	13.589	3.573	6.220	2.228	3.552
Media_total	11.984	12.135	12.384	12.974	12.468	12.083	11.974	12.374	12.523	12.329
Access_user	6.822	6.915	6.944	7.002	7.263	7.374	7.549	7.669	7.734	7.276

(source: China Finance and Economics database).

annual average of carbon dioxide emission intensity during the statistical period is 3.552. The decline in carbon dioxide emission intensity after 2017 is very obvious. It should be noted that before 2017, although the carbon dioxide emission intensity of Chinese agricultural listed companies was at a low level, it was mainly due to the small scale of non-modern agriculture and low carbon dioxide emissions. In 2017, the central government of China put forward the concept of "agricultural modernization" in the government work report for the first time, and actively advocated the development of "green agriculture". Later, a group of large agricultural listed companies with modern characteristics and practices to reduce carbon dioxide emissions grew rapidly. Therefore, the carbon dioxide emission intensity of agricultural listed companies shows the characteristics of the decreasing year by year and improving carbon dioxide emission performance.

Among the independent variables of network attention, the average value of *Media_total* is 12.329, and the standard deviation is 0.837, indicating that China's agricultural listed companies have more widespread network concerns. Another independent variable, *Access_user*, is 7.276, with a standard deviation of 0.774, which also shows that there are many network users in the cities where agricultural listed companies are located, which brings a certain scale of network attention. Combined with the temporal distribution description of network attention in Table 3, *Media_total* and *Access_user* values are increasing year by year, which shows that Chinese agricultural listed companies are increasingly concerned by the network. From the perspective of control variables, the mean values of *Epap*, *Lev*, *Size*, *Growth*, *Firmage*, and *Board* variables are 0.006, 0.443, 21.765, 0.114, 2.842, and 2.103 respectively, and the standard deviations are 0.078, 0.213, 1.033, 0.457, 0.328, and 0.228 respectively. This conveys the real information that China's agricultural listed companies have less environmental protection punishment, use financial leverage, relatively large scale, rapid development, long establishment time, and considerable internal governance. As an adjusting variable, the average value of *Epinvest* is 15.545, and the standard deviation is 1.572, indicating that there are certain differences in the environmental protection investment of different agricultural listed companies. In general, the results of the descriptive statistics are basically in line with the realistic characteristics of environmental governance and network concerns of China's agricultural listed companies. In addition, before the benchmark test, we also conducted a correlation coefficient test. The variance inflation factor was significantly lower than 10, and there was no serious multicollinearity problem among the main variables.

4.2 Benchmark test

Due to the pressure of reputation, punishment, and market caused by network concern, agricultural listed companies are sensitive to green development issues and are prone to make more environmentally friendly behaviors, reduce environmental risks of enterprises and improve the competitiveness of carbon dioxide emissions. This makes network attention help to promote the performance of carbon dioxide emissions. Table 4 reports the results of the benchmark test based on model 2). Columns 1) and 2) examined the overall impact of the network attention of China's agricultural listed companies on the performance of carbon dioxide emissions. In order to judge the effectiveness of the lag instrumental variables, we first test the insufficient identification and weak instrumental variables of the two instrumental variables. The total amount of network attention in the lag period *Media_total(-1)* and the total number of urban broadband users in the lag period *Access_user(-1)* is a tool variable, and the *p*-value of the under-identification test (Kleibergen-Paap rk LM statistic) is 0.026 and 0.000 respectively. The estimated results reject the original hypothesis, indicating that the instrumental variables are related to the original explanatory variables. In addition, the test results of weak instrumental variables (Cragg-Donald Wald F statistic) of the two instrumental variables are greater than 10, which are 97.218 and 158.535 respectively, indicating that the selection risk of instrumental variables is low. From the overall regression results, in column 1) and column 2), the estimated coefficients of *Media_total* and *Access_user* are significantly negative, indicating that the increasing network attention has significantly reduced the carbon dioxide emission intensity of agricultural listed companies and brought about better carbon dioxide emissions performance.

4.3 Heterogeneity test results and analysis

Table 5 reports the results of the heterogeneity test. Columns 1)–4), 5)–8), and 9)–(12) examined the impact of network attention on carbon dioxide emission performance of agricultural listed companies based on the heterogeneity of network, region, and property rights. Columns 1) to 4) are divided into PC concerns and mobile internet concerns according to the main sources of the total number of network searches. The network heterogeneity test results show that the independent variable *Media_total* and *Access_user* are only significantly negative in column 3) and column 4), with estimated coefficients of -4.921 and -2.086 respectively, indicating that the network focus mainly on mobile internet search has a more significant effect on the improvement of carbon dioxide emission performance of agricultural listed companies. From the regression of regional heterogeneity of column 5)–8) subsamples, the

TABLE 4 Results of benchmark regression.

Variable	Emp_intensity	
	(1)	(2)
Media_total(-1)	-4.511* (-1.75)	
Access_user(-1)		-0.985*** (-2.97)
Epap	1.049 (0.57)	0.893 (0.59)
Lev	-2.603 (-0.49)	-4.851 (-0.77)
Size	-3.623*** (-3.03)	-5.018*** (-3.02)
Growth	-1.307** (-2.00)	-2.012* (-1.68)
Firmage	2.647* (1.67)	1.442 (1.07)
Board	5.659* (1.94)	4.027 (1.57)
Constant	118.317*** (2.76)	106.208*** (3.02)
Year	control	control
Observations	324	324
Adj R-squared	0.367	0.301

Note: 1) ***, **, and * respectively represent significant levels of 1%, 5%, and 10%; 2) The T values are in parentheses; 3) The regression results in the table have been corrected by the cluster at the regional level. The same is below.

independent variable *Media_total* and *Access_user* are significantly negative in column 6), column 7), and column 8), and the estimated coefficients are -1.086, -6.051 and -0.573 respectively. At the same time, the coefficient difference test of variable *Access_user* in column 6) and column 8) shows that there is a significant difference in the estimated coefficient of independent variables, that is, the estimated coefficient of independent variables in the central and western groups is more significant. The above shows that network attention has a more significant impact on the carbon dioxide emission performance of agricultural listed companies in the central and western regions. From the regression of property right heterogeneity of subsamples 9) to (12), the independent variable is significantly negative in columns 9) and (10), and the estimated coefficients are - 7.397 and - 1.864 respectively, indicating that network attention has a more obvious impact on the environmental governance behavior of state-owned agricultural listed companies. Therefore, there is the network, regional, and property heterogeneity in the promotion of China's network attention on the carbon dioxide emission performance of agricultural listed companies.

In fact, with the rapid development of the internet, the external governance effect of network attention on environmental protection is increasingly obvious (Schrlau et al., 2011). Compared with the PC's attention, using mobile internet can get rid of location restrictions and search more convenient and accurate, which makes the attention from mobile internet not only far exceed the PC's attention in magnitude, but also exert more obvious and focused network pressure (Wang et al., 2022), bringing more powerful carbon dioxide emission control effect than PC's attention. In addition, the eastern coastal provinces are the regions where China opened up earlier and changed to a market economy. The agricultural enterprises in this region have a strong concept of green environmental protection. However, agricultural

enterprises in the central and western regions are often inferior to those in the eastern coastal regions in terms of environmental protection awareness and behavior performance (Komarek et al., 2015), which makes the improvement effect of network attention on the carbon dioxide emission performance of agricultural enterprises in the central and western regions more obvious. Finally, the nature of property rights of Chinese enterprises includes state-owned and private enterprises, and there are significant differences in the motivation and motivation of corresponding emission reduction (Wu et al., 2019). Compared with private agricultural listed companies with the primary goal of chasing profits, state-owned agricultural listed companies also shoulder the goal of fulfilling political tasks and social responsibilities. It has more power to actively respond to network concerns and public expectations by reducing other greenhouse emissions per unit product, making the network focus more significant in improving the carbon dioxide emission performance of state-owned agricultural listed companies.

4.4 Mechanism test results and analysis

In recent years, promoting green and low-carbon transformation has been regarded as an important direction for enterprises to move towards high-quality development and has attracted the attention of Chinese netizens. In this context, agricultural listed companies will pay more attention to environmental protection issues and have the motivation to respond to network concerns, to invest more costs to promote environmental protection, which makes environmental protection costs play a mechanistic role for the network to focus on improving the performance of carbon dioxide emissions. On the one hand, a higher degree of network attention can help alleviate the degree of environmental information asymmetry of agricultural listed

TABLE 5 Results of heterogeneity regression.

Variable	Emp_intensity				Emp_intensity				Emp_intensity			
	PC		Mobile internet		East		Midwest		State-owned		Private-owned	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Media_total(-1)	-0.714 (-0.95)		-4.921** (-1.85)		-0.145 (-0.34)		-6.051*** (-2.68)		-7.397*** (-4.73)		0.786 (1.52)	
Access_user(-1)		-0.261 (-1.63)		-2.086** (-2.50)		-1.086* (-1.79)		-0.573** (-1.97)		-1.864*** (-2.93)		-0.657 (-1.58)
Epap	0.000 (0.00)	0.000 (0.00)	1.208 (0.64)	0.639 (0.41)	0.000 (0.00)	0.000 (0.00)	1.521 (0.59)	2.014 (0.93)	2.123 (0.81)	1.443 (0.92)	0.000 (0.00)	0.000 (0.00)
Lev	-4.231 (-1.00)	-5.180 (-1.09)	-2.540 (-0.46)	-4.919 (-0.78)	1.306 (0.42)	0.181 (0.07)	-5.376 (-0.78)	-7.370 (-0.92)	-11.735* (-1.72)	-14.494* (-1.90)	2.175 (0.62)	2.812 (0.84)
Size	-2.576*** (-2.87)	-2.640*** (-3.10)	-3.623*** (-2.89)	-5.430*** (-3.07)	-1.651** (-2.45)	-2.132*** (-2.64)	-4.006** (-2.39)	-5.974*** (-2.98)	-2.465** (-2.47)	-6.342*** (-3.58)	-3.863*** (-3.10)	-3.893*** (-3.12)
Growth	-5.808*** (-3.41)	-5.112*** (-2.85)	-0.963 (-1.35)	-1.963 (-1.60)	-0.387 (-0.54)	0.095 (0.07)	-1.004 (-1.28)	-2.199 (-1.54)	-2.372** (-2.19)	-4.476*** (-3.37)	-0.319 (-0.35)	-0.299 (-0.34)
Firmage	-0.930 (-0.87)	-1.412 (-1.33)	3.428* (1.95)	2.287* (1.65)	1.878 (1.04)	1.462 (1.11)	5.777** (2.36)	3.138 (1.40)	-2.442 (-0.81)	-4.667 (-1.45)	3.138 (1.59)	3.203* (1.67)
Board	-0.881 (-0.43)	-1.438 (-0.61)	6.684** (2.05)	4.403 (1.49)	2.764* (1.79)	1.359 (1.44)	8.793** (2.05)	6.514* (1.85)	5.391 (1.47)	4.495* (1.77)	4.233 (1.40)	4.107 (1.44)
Constant	73.176*** (2.77)	70.136*** (2.99)	117.734*** (2.86)	121.973*** (3.07)	28.147** (2.44)	49.740*** (2.79)	131.126*** (3.47)	115.323*** (3.33)	148.155*** (3.93)	156.633*** (3.31)	57.967*** (3.20)	73.482*** (3.47)
Year	control	control	control	control	control	control	control	control	control	control	control	control
Access_user(-1) coefficient difference test	-	-	-	-	-	-24.440*	-	-24.440*	-	-	-	-
Observations	35	35	289	289	118	118	206	206	149	149	175	175
Adj R-squared	0.627	0.640	0.373	0.310	0.369	0.422	0.430	0.330	0.500	0.344	0.352	0.354

TABLE 6 Results of mechanism testing.

Variable	Emp_intensity	
	(1)	(2)
Media_total(-1)	31.326** (2.16)	
Access_user(-1)		3.083 (1.48)
Epinvest(-1)	27.939** (2.29)	2.376** (2.18)
Media_total(-1)*Epinvest(-1)	-2.215** (-2.21)	
Access_user(-1)*Epinvest(-1)		-0.260* (-1.95)
Epap	1.145 (0.74)	0.742 (0.52)
Lev	-2.878 (-0.64)	-4.182 (-0.70)
Size	-3.757*** (-3.25)	-5.081*** (-3.06)
Growth	-1.423** (-2.48)	-2.022 (-1.61)
Firmage	2.836* (1.86)	1.547 (1.13)
Board	4.044* (1.71)	3.732 (1.59)
Constant	-327.731** (-1.96)	70.609* (1.92)
Year	control	control
Observations	324	324
Adj R-squared	0.402	0.306

news, which will make agricultural listed companies fully feel the public's environmental protection requirements, and to alleviate the pressure on environmental protection (Hu et al., 2019), increase the investment in environmental protection costs, enhance the "carbon reduction and consumption reduction" efforts, to meet the social environmental protection requirements.

Based on model 2), add the *Epinvest* regulatory variable representing the environmental protection cost input. Via *Media_total(-1) * Epivest(-1)* and *Access_user(-1) * Epinvest(-1)* two interaction terms are used to test the possible mechanism of environmental protection investment. Table 6 reports the mechanism test results. In column 1), the estimated coefficient of *Media_total(-1) * Epivest(-1)* is -2.215, and it is significantly negative at the level of 5%. This shows that the investment in environmental protection has adjusted the relationship between network attention and carbon dioxide emission intensity of agricultural listed companies, and has significantly promoted the reduction of carbon dioxide emission intensity of agricultural listed companies. In addition, in column 2), the estimated coefficient of *Access_user(-1) * Epinvest(-1)* is also significantly negative, which further confirms the above conclusion. To sum up, the investment in environmental protection costs will strengthen the inhibition effect of network attention on the unit carbon dioxide emissions of agricultural listed companies.

4.5 Robustness test

In the part of the robustness test, we focus on mitigating possible estimation bias caused by variable selection and model setting. The robustness regression by replacing key variables, adjusting the model, and deleting the samples of special years. First, replace variables and models. Considering that network attention is not

companies, enable them to detect and fill gaps while enhancing environmental awareness (Lo et al., 2012), and help enterprises reasonably increase environmental protection investment expenditure; On the other hand, highly concerned enterprises have a higher exposure probability of environmental protection

TABLE 7 Robustness test results.

Variable	Emp_intensity		
	Replace variables and models	Non-linear model regression	Delete special year regression
	(1)	(2)	(3)
Pc_total(-1)	-4.619* (-1.67)		-2.050** (-2.00)
Pc_total(-1)2		-0.329 (-1.34)	
Epap	-1.592*** (-2.85)	-1.610** (-2.57)	-1.110 (-1.59)
Lev	-7.846*** (-2.96)	-7.402*** (-2.63)	-6.722* (-1.77)
Size	-1.319 (-0.77)	-1.761 (-1.10)	-3.946 (-1.50)
Growth	-3.063*** (-3.56)	-3.473*** (-2.83)	-2.127** (-2.09)
Firmage	7.792** (2.48)	9.114*** (2.79)	18.279** (2.50)
Board	-0.334 (-0.09)	-0.521 (-0.14)	-3.150 (-0.67)
Constant	39.432 (1.49)	30.386 (1.15)	59.081 (1.52)
Fixed Effect	control	control	control
Observations	324	324	245
Adj R-squared	0.137	0.102	0.075

only reflected in the annual search volume based on mainstream search engines, but also reflected in the amount of attention from computers and mobile internet. Therefore, referring to Francesca et al. (2017), we set into the computer side annual network attention (*Pc_total*) alternative indicators for regression; Second, transform the model. Due to the possible non-linear relationship between the network attention and the carbon dioxide emission performance of agricultural enterprises, referring to Shakil (2020), the original model introduced the quadratic term of the independent variable (*Pc_total2*) to test again; Finally, delete the special year regression. Since 2019, the central government of China has issued the "Regulations on the Supervision of Central Ecological Environment Protection" and implemented a more explicit ecological environment protection supervision system. The government's increased environmental protection supervision may have a disturbing impact on the carbon dioxide emission performance of agricultural enterprises. Referring to the practice of Zhan et al. (2022), the samples in 2019 and 2020 were excluded from robustness testing. From the results of the robustness test in Table 7, in column 1), after replacing the variable and model, the variable *Pc_total* estimated coefficient is still significantly negative. In column 2), after non-linear model regression, there is no significant non-linear relationship between annual PC network attention (*Pc_total*) and carbon dioxide emission performance (*Emp_intensity*), indicating that the original linear regression results are reliable. In column 3), after deleting the special year sample, the variable Pc_total estimated coefficient is still significantly negative. The above tests show that the previous conclusions are relatively robust.

5 Conclusion and suggestions

China is the largest developing country in the world and the country with the largest number of internet users. The environmental governance effect of its network attention deserves attention. This paper focuses on the agriculture sector, which has been neglected in the past and uses the unique network attention data in China to study the impact of network attention on the carbon dioxide emission performance of agricultural listed companies. The research found that: 1) By measuring the carbon dioxide emission intensity of China's agricultural listed companies, it is found that the overall carbon dioxide emission intensity is decreasing year by year and the carbon dioxide emission performance is improving; 2) Based on the instrumental variable model, the impact of network attention on the carbon dioxide emission performance of agricultural listed companies was examined. It was found that the increasing network attention significantly reduced the carbon dioxide emission intensity of agricultural listed companies, and brought better carbon dioxide emission performance; 3) Based on the heterogeneity analysis, it is found that there are network, regional, and property heterogeneity in the promotion of China's network attention on the carbon dioxide emission performance of agricultural listed companies; 4) Taking environmental protection investment as the potential mechanism, the test found that environmental protection investment will strengthen the inhibition effect of network attention on carbon dioxide emissions per unit of agricultural listed companies.

The research conclusions provide useful ideas and wisdom for China and other developing countries to promote carbon-neutral action, tap the potential of emission reduction in the agricultural sector, and give full play to the emission reduction effect of network governance. We suggest that: 1) developing countries should give full play to the role of informal environmental regulation in environmental governance in carbon neutral action, encourage non-governmental organizations to participate in environmental protection publicity, open channels for the public to express suggestions related to environmental protection issues, and increase the network attention and response to pollution issues; 2) Local governments should earnestly fulfill the obligations of the first responsible unit for implementing the carbon neutrality task in the region, scientifically design the system and mechanism for regional coordinated control of carbon dioxide emissions, encourage the green and low-carbon development of agriculture, and other sectors, and do good in guiding the public opinion of the carbon neutrality network; 3) Agricultural listed companies should pay attention to the carbon dioxide governance effect of network concern, actively look at the environmental pressure brought by network concern, actively respond to the environmental protection opinions of network concern and increase the investment in environmental protection costs, promote the improvement of carbon dioxide emission performance, and promote the green and high-quality development path.

Finally, this paper may have limitations in the following aspects, which need to be deepened in the future: First, according to academic practice and data availability, this paper uses carbon dioxide emission intensity as an alternative variable of environment-related performance. If more sufficient data can be obtained in the future, it can be further expanded to other environmental pollution performance levels such as soil and water; Second, based on the characteristics of China's online reality, this paper examines the impact of online attention on carbon dioxide emissions performance based on Baidu Search Index. In the future, we can try to use other online social media data to enrich research.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

JC: Original writing, Editing and Revise paper HS: Original writing, Editing and Revise paper, Supervision, Data collection and analysis.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1136318/full#supplementary-material

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