

Impact of Digitalization on Environmental Performance: The Role of Organizational Green Culture and R&D in SMEs

Abstract

The public is focused on the impact of digitalization on environmental problems. People are still searching for ways to overcome pollution and environmental disruption. There are many research related to digitalization and environment. But it is still blank for digitalization and companies' environmental performance, especially in SMEs. In this research, to figure out if environmental performance would be affected by digitalization, we explored the relationship between these two items. The impact of organization green culture and R&D are also being considered in this research. The result shows that digitalization has a positive effect on environmental performance. Digitalization affect the environment through company's organizational green culture and green transformations. Research and development have moderating effects on digitalization and environmental performance. Digitalization affects environmental performance more when research and development level is higher. The findings of this study can help the companies build strategies to improve their environmental performance and prompt environmental protection.

Key words: Digitalization, Environment, R&D, SEM, SMEs

1 Introduction

In recent years, the world is changing to digital space (Telukdarie et al., 2023). Typhoid and cholera which is considered as waterborne diseases are caused by environment pollution (Siddiqua et al., 2022). Environment protection has been a global popular discussed topic since people realized that environmental problems affect society a lot. In the discussion about environment, digitalization is mentioned as a method to keep sustainable development (Y. Li et al., 2020).

Digital technique starts to become crucial component in services of companies in a tightly connected global situation (Ben Khalifa, 2023). Digitalization was saved plenty of firms from bankrupt during Covid-19 (Santos et al., 2023). It affects

companies in their products, services, and operation a lot. Almost all companies start using digitalization in their work to explore advantages of digital technologies (Tagscherer, 2023).

Human's development caused chemicals which is harmful for human's health (Shetty et al., 2023). When the basic needs of people were satisfied, people with high income started to deserve a high-quality living environment (Rashid Gill et al., 2018). There is a new trend that people require sustainable development during production. Sustainability is to build our society and leave enough resources for the next generation to develop at the same time. This concept has been written in constitutions and laws of many countries and used as rules in business activities (Ruggerio, 2021). The number of natural resources and the extent of economic growth are threatened by climate change, natural disasters, and other environmental problems. Firms started to incorporate green culture into their firm culture (Aggarwal & Agarwala, 2023a).

Environmental protection is considered as an aspect to evaluate companies. Corporate stakeholders care about the importance of corporate environmental performance. The rating agency is more likely to give higher scores to firms with high environmental performance level. Environment protection situation affects investing credit rating of companies (Hu et al., 2024).

Firms' investments in green intelligence affect their environmental performance (Yusliza, 2020). Research and development (R&D) can prompt economic sustainable development. R&D also has a positive relationship with labor productivity (Ben Khalifa, 2023). It helps to increase company competitiveness and working efficiency. And there are ways to solve climate change and clean energy problems through using R&D (Minviel & Ben Bouheni, 2022).

Digital level has a negative relationship with environment performance at the beginning, after that these two items have significant positive correlation (Yang et al., 2023a). It can help to treat solid emissions and sewage, raise public awareness of environmental protection and protect biological diversity. The impact of digitalization on environmental health and ecosystem vitality is significant. Using digital technology

in business is helpful for solving environmental issues (Ha et al., 2022a).

Building firm culture which encourages members to trust and cooperate with each other help information sharing faster. It is beneficial for high technological companies to keep their long-term competitiveness (Lam et al., 2021). Companies have added environmental protection into the firm green culture. It makes the employees concerned more about environmental issues and treated environmental problems more seriously. The firm green culture can help the company to deal with waste problems and make a green change in their work (S. Wang et al., 2022).

Carbon emission reduction for firms has been a trend in the world. As a result, many firms are undertaking green transformation to adapt to new business requirements. Green Transformation is affected by government, markets and technology (Feng et al., 2024). The governments publish policies to prompt green development, and to make firms meeting the environmental demands of customers. Technology makes it possible for companies to reduce carbon emissions, use clean energy and restore biodiversity (L. Wang et al., 2022).

Existing literature shows when the digitalization developed to a certain level, there is a positive correlation between the level of digitization and the environmental performance (Zhang & Zhao, 2023). Large successful companies are pouring money into digitalization to improve their innovation capability and competitiveness (Abbas et al., 2024). But Small and medium-sized enterprises (SMEs) can affect more than our thoughts in digitalization and environment performance. There are about 90% of clean tech enterprises are SMEs in the United Kingdom. They played an important role in the green transformation (Ardito, 2021). While researching related studies, we found that there are not enough researches used the background of SMEs. The importance of SMEs in the field of digitalization and environment protection is underestimated.

In the previous literature, they are faded to mention the impact of R&D on the relationship between digitalization and environmental performance. It is rarely for studies to use research and development as a moderator variable. We assume that when the company spent more on R&D, the effects of R&D on environmental performance were strengthened and the effects of digitalization were weak. There was also not

enough researches firm green culture and green transformation as the mediator variable between digitalization and environmental performance. They ignored that digitalization ~~could~~ is able to change culture in the company and influence the use of green knowledge, skills and technology. It finally increases the performance of the company in protecting the environment. There is few research focused on small and medium entities, and we used SMEs as our object of study.

To fill these study blanks we mentioned, in this study, we tried to answer the following questions:

1. Can digitalization in firms solve environmental problems and make SMEs have better environment performance?
2. If development and research ~~can~~ moderate the relationship between corporate digitization and environmental performance?
3. Can digitalization affect the environmental performance of SMEs through firm green culture and green transformation?

This research aims to explore the relation between digitization and environmental performance. Now people are searching for methods to solve environmental problems. This study helps people to figure out ways to make companies act better in the green field. There is a correlation between enterprise innovation capability and enterprise environmental performance (Yusliza, 2020). This study also explore the relationship between them and comprehensively explore the impact of digitalization on environmental performance.

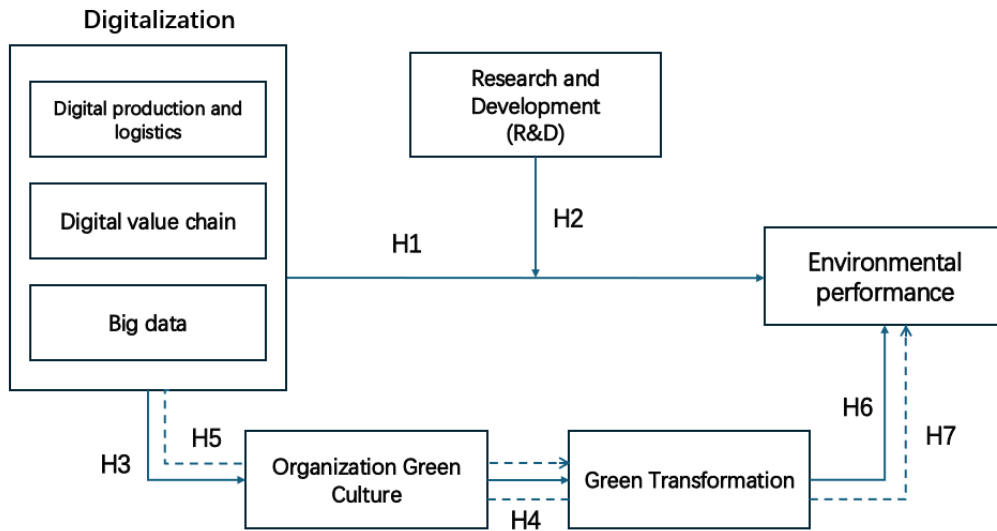


Figure 1: Research model

2. Literature review and hypothesis development

2.1. The relationship between digitalization and environmental performance

The digitalization have positive impact on the environment with the “dual carbon” target(Feng et al., 2024). During the process of digital transformation of entities, the COD emission was obviously reduced. This impact is more significant in heavy-polluting industries and non-capital-intensive industries(Wen et al., 2021a). By working on Environmental performance index (EPI) in many different perspectives, research found that digitalization affects environmental well-being and ecosystem resilience. But this effect was obviously weakened when the COVID-19 is spread in around the world(Ha et al., 2022b). Digital transformation has positive affect on the environment, but there were also negative impacts when the digitalization was developed too much. The digital development itself caused new environmental pollution. Research also found that in countries with strict rules the negative impacts of the digitalization were delayed later combine with countries with loose institutions(Ahmadova et al., 2022). In textile and apparel industry, the nexus between digitalization and environmental performance is a U-shaped curve. At the beginning time, their correlation is negative(Yang et al., 2023b). The disadvantages caused by over-digitalization of

entities can be reduced or counteracted by digital methods, product, or service(Haq & Huo, 2023). There are both positive and negative effects between digitalization and the environment according to these articles.

In our research we used digital production and logistics, digital value chain and big data as the scale to measure digitalization. The needs of specialization caused a lot of changes in digital production and logistics(Pan et al., 2021). The digital management caused a transformation in working process in logistics. The digital developing can affect global value chain. The internet has become an important platform and intermediary of the digital value chain(Butollo et al., 2022). Big data is the amount of data created during the processing of the company's work. It is also related to analyzing data. Big data is considered as one of key tools in the future. It can help companies to innovate new products and services and make them more competitive(Radicic & Petković, 2023). According to these studies, we assume that,

H1: digitalization level has a positive relationship to environment performance in the SMEs.

2.2. Research and development (R&D) and environmental performance

Supporting innovation is a way to improve the use of new technology, reducing greenhouse gas emissions, and promoting the use of clean energy. The governments give firms preferential tax policy related to environment as investment of green innovation and sustainable development(Ullah et al., 2023). Research and Development have a more and more important impact on CO₂ Emissions, Ecological Footprint (ECF) and Load Capacity Factor (LCF). It means that innovation affects the environment more as the time changes (Kartal & Pata, 2023). Green innovation can enhance the capability to realize the sustainable target for entities (Abbas & Khan, 2023). Green knowledge management (GKM) enhances the sustainable performance and prompts the green innovation to increase the extent of environment performance (Abbas & Khan, 2023). Natural disasters lead to a transformation from traditional innovation to green innovation. This caused an improving of the environmental performance (Ma et al., 2024).

H2: R&D has a positive effect on environment performance.

2.3. Digitalization and organization green culture and green transformation

The more far-sighted managers find the value of an organization's information value earlier. Digitalization inside the company has a positive effect to the organization(Autio et al., 2021). Organizational culture is the foundation of sustainable progress and digital transformation of a company. Development of organizational culture is a necessary step to increase the level of digitalization(Isensee et al., 2020). The digital business transformation prompted the company's organizational performance. It led to a revolution in the structure and culture of the organization(Sestino et al., 2020). Using social media marketing strategy improves learning and innovation capability of organizations. A company needs to build an environment to allow the development of IT. The environment should have leaders supporting digitalization, employees familiar with digital technology, a flexible organization culture and capability to creating(Eller et al., 2020). The company needs a new culture to practice digitalization. In that culture, employees are willing to learn about new technology to work, share their information and be creative in their work(Martínez-Caro et al., 2020).

H3: Digitalization positively affect organization green culture

The organization culture is built and spread by the manager team and bring it to all around the company to lead the firm's target. Organization culture includes the thoughts, ideals and value of a company. Organization Green culture (OGC) is the organization culture created based on green strategy. The OGC is leading stuffs in the company focus on green problems(C.-H. Wang, 2019). Making employees own environmental awareness is benefit for the company to achieve their green target. Organization culture is important to drive the firm. It takes the company to a sustainable future which is far away from pollution abatement(Aggarwal & Agarwala, 2023b). Green transformation is a win-win strategy in the industry. Companies can reduce carbon emission and build green total-factor at the same time. People should realize that the earth need time to recover, and sustainable development is very crucial in the world(Thomas & Suresh, 2024). Organization green culture affects green transformation positively. It can also lead to a progressing of the innovation of green products. The manager can

communicate their thoughts about green development to the members of the company. Firms have a clear goal in green field are easier to achieve green transformation(Chen et al., 2020).

H4: Organization green culture positively affects green transformation.

Organization green culture is a faith to guide the company to build an environmentally friendly standard of behavior. If the stuffs in the company, try their best work to avoid harm the environment this company can be considered that they are using the organization green culture (Al-Swidi et al., 2021). The organizational culture can be changed by new technology (Isensee et al., 2020). Digitalization is one of them. Digitalization transformation changed the office style and business model of companies. It led to work style using of technology and business focus on customer's needs(Hanelt et al., 2021). Digitalization transformation can affect the culture inside the company(Isensee et al., 2020). Employees in a company can learn new things from other people around them, especially their leader. Environmental awareness can spread in a top-down way in the entity(Al-Swidi et al., 2021). So, putting green strategy in the company's culture can impact the green actions of the employees and prompt green transformation. The company should motivate employees paying attention to green thoughts and green behaviors (Hooi et al., 2022). The conclusion is:

H5: Organization green culture mediates between digitalization practices and green transformation.

2.4. Organization green culture and green transformation and environment performance

The industry green transformation is the important motivation for development of industry. The discussion and exploration about the green transformation is an inevitable trend. The development of industry needs to transform to low carbon emission, and high effective mode of production (Ran et al., 2023). Using cleaner production and energy can reduce the risk of leaking fossil and prompt low carbon emission(Fan et al., 2023). Building green finance is also a way for green transformation. It can help companies keep sustainable development(Sarpong et al., 2023). Whether to use ISO

Environmental management system can be another standard to measure green transformation(Feng et al., 2024). International Standard Organization (ISO) can help companies and countries to measure and control the resources and services well to get the environmental and economic performance(Gomes et al., 2023). The promotion of green transformation reduce the pollution and bring benefits to the environment(Madaleno et al., 2022). The green transformation and environmental performance have a positive relationship (Z. Wang et al., 2024).

It is not enough for a company if only their leaders focus on the environment. Putting green awareness into company culture can affect all staff, not only the managers(Ali et al., 2023). Organization culture can help the company spread the idea of environmental protection in normal operating. When sustainability becomes the main thoughts of the culture, all company will follow the culture and improve the environmental performance(Fok et al., 2023). Organization green culture can make employees focus on green behavior and improve the green capability and skills in the company. Learning green knowledge and skills is considered more and more important in industries. Companies usually use green technology to increase the efficiency of resource and reducing environmental pollution(Sahoo et al., 2023). Both the academia and Industry realized that this sustainable capability can help the company to develop the environmental performance(Ali et al., 2023; Hooi et al., 2022).

H6: Green transformation has a positive relationship to environmental performance.

H7: Green transformation mediates between organization green culture practices and environment performance.

3. Research Methodology

3.1 Data analysis approach

In this research, we used the SPSS 22, AMOS and SPSS process as the main approach to analyze the data. We followed the structural equation modeling (SEM) method. First, we collected data by questionnaires and cleaned the data to make sure that all data is effective. We deleted data from large companies to focus on SMEs. Then we statistics the data and get a general result about demographic questions. We also do the confirmatory factor analysis (CFA) to tell if the model fits well and test the latent variables' relationship. Next, we used the CFA to test if our question can effectively test our target items(Singh & Verma, 2024). After that, we checked the reliability and validity of answers. To make sure that the questions fit our study background. Moderator and mediator is tested by SPSS 22 and SPSS process. Mediator analysis used Bootstrap Which is created by Andrew F. Hayes(Hayes, 2022). It is to test whether the variables have mediating and moderating effects.

3.2 Data Collection

This research collected data from small and medium enterprises (SMEs) in China. Questions covered demographic questions and basic information about firms and scales about independent variable, dependent variable, mediator variable and moderator Variable. We used the questionnaire to measure the extent of digitalization, R&D, organization green culture, green transformation and environmental performance in the companies. We combined and adjusted our questionnaire from the published journals. The scales are designed as 1=Strongly Disagree, 2=Moderately Disagree, 3=Neutral, 4=Moderately Agree, 5=Strongly Agree. This research is quantitative research, all the questions except the demographic questions are measured from 1 to 5. And then translated the questionnaire into Chinese and attached the research instructions. The questionnaire was posted on websites and social media. We set the demographic questions in the questionnaire including the answer's age, education level and position in the company. The general statistics are in table 1. We want to make sure that our data

comes from the SMEs. Managers in the SMEs have more power and their thoughts can impact the companies in more perspectives and

deeper. The companies' belief is always decided by the managers and managers have an original understanding about it(Tan et al., 2025). Employees in the company can affect the achievement of the organization's environmental strategy. So the employees are encouraged to participate in the activities related to the company's environment expectation(Z. Hameed et al., 2020). We also collected information about companies, for example, the main business of the company, how many employees there are in the company and the revenue of the company. These data helped us to have a general view of the industries. According the National Bureau of Statistics the small and medium enterprises (SMEs) in China have standard numbers of employees and revenue(National Bureau of Statistics, 2023). So, we selected the SMEs companies based on their information.

3.3 Measurement and pre-testing

This study used existing scales to measure. All the questions in our measurement model come from existing research. They have all proved that they are effective, valid and reliable.

Digitalization: We used the scales of Radicic and Petković(Radicic & Petković, 2023) measured the digital production and logistics, digital value chain and big data by 3 questions. The Cronbach's alpha scores of these items are 0.782.

Environment Performance: There are 8 questions in the scale and it is coming from the research of Aggarwal and Agarwala(Aggarwal & Agarwala, 2023c). The Cronbach's alpha scores of these items are 0.921.

R&D: We used 6 questions. One of them also comes from Radicic and Petković in 2023. Other 5 questions is used by Hameed (W. U. Hameed et al., 2018) to measure the research and development level of the company. The Cronbach's alpha scores of these items are 0.888.

Organization green culture: To test the organization green culture in the

Variable	Values	Percent
Age	<20	7.19%
	20~35	27.29%
	36~45	24.67%
	46~55	22.22%
	>55	18.63%
Education	Technical secondary school, high school or below	21.73%
	Bachelor's degree	48.04%
	master's degree	18.95%
	doctorate	11.27%
Position	Ordinary and general staff	45.10%
	Technical personnel	26.63%
	Middle management	18.30%
	Senior management	9.97%
Industry	Information technology	7.03%
	Transportation	5.72%
	Wholesale sales	0.65%
	Science and technology	3.10%
	Manufacturing industry	8.82%
	The building	18.30%
	Retail sales	19.93%
	Logistics	19.28%
	Real estate	17.16%
Number of staff	<20	22.22%
	20~299	43.63%
	300~999	34.15%
Number of revenues	<3millions	22.88%
	3millions~20millions	42.32%
	20millions~400millions	34.80%
Note(s): N = number of respondents		Table1: Sample characteristics(N=612)

company we used questions of Wang(C.-H. Wang, 2019) including 6 questions. The Cronbach's alpha scores of these items are 0.892.

Green transformation: This item is tested by scale of Feng by 8 questions(Feng et al., 2024). Respondents are required to select their companies' extent for green transformation. The Cronbach's alpha scores of these items are 0.918.

3.4 Measurement model, reliability, and validity analysis

Items	Factor code	Factor loading
Digitalization ($C-\alpha = 0.782$)	DIG1	0.748
	DIG2	0.763
	DIG3	0.714
Environment Performance ($C-\alpha = 0.921$)	EP1	0.740
	EP2	0.746
	EP3	0.761
	EP4	0.734
	EP5	0.772
	EP6	0.771
	EP7	0.762
	EP8	0.768
Research and Development ($C-\alpha = 0.888$)	R&D1	0.709
	R&D2	0.732
	R&D3	0.752
	R&D4	0.734
	R&D5	0.754
	R&D6	0.713
Organization green culture ($C-\alpha = 0.892$)	OGC1	0.790
	OGC2	0.772
	OGC3	0.771
	OGC4	0.746
	OGC5	0.763
	OGC6	0.783
Green Transformation ($C-\alpha = 0.918$)	GT1	0.735
	GT2	0.722
	GT3	0.783
	GT4	0.751
	GT5	0.768
	GT6	0.769
	GT7	0.701
	GT8	0.744
Note(s): $C-\alpha$ = Cronbach alpha		Table2: Factor analysis

The result of factor analysis is included in Table 2. The Cronbach alpha is larger than 0.7, all loading factors are larger than 0.7. Kaiser-Meyer-Olkin Measure of Sampling Adequacy is 0.958. The respond of the questionnaire is reliable and internally

consistent. High loading factor shows these questions have a strong capability to explain the latent variables. KMO is larger than 0.9. It means that this sample is very suitable for factor analysis and structural equation modeling (SEM).

Correlations		EP	DIG	R&D	GT	OGC
Pearson Correlation	EP	1				
	DIG	0.47**	1			
	R&D	0.434**	0.483**	1		
	GT	0.477**	0.452**	0.508**	1	
	OGC	0.356**	0.362**	0.433**	0.323**	1
Summary statistics						
Number of items		8	3	6	8	6
Mean		3.572	3.845	3.628	3.683	3.754
Standard deviation		1.0350	0.9616	1.0306	0.9926	0.9754

Table3: Descriptive statistics and correlations

All coefficients between variables are positive in Table 3. The p-value of them is smaller than 0.01. So, the correlations of these 5 variables are significant. The coefficients of items are of an appropriate value. It is not extremely large or small(Singh & Verma, 2024).

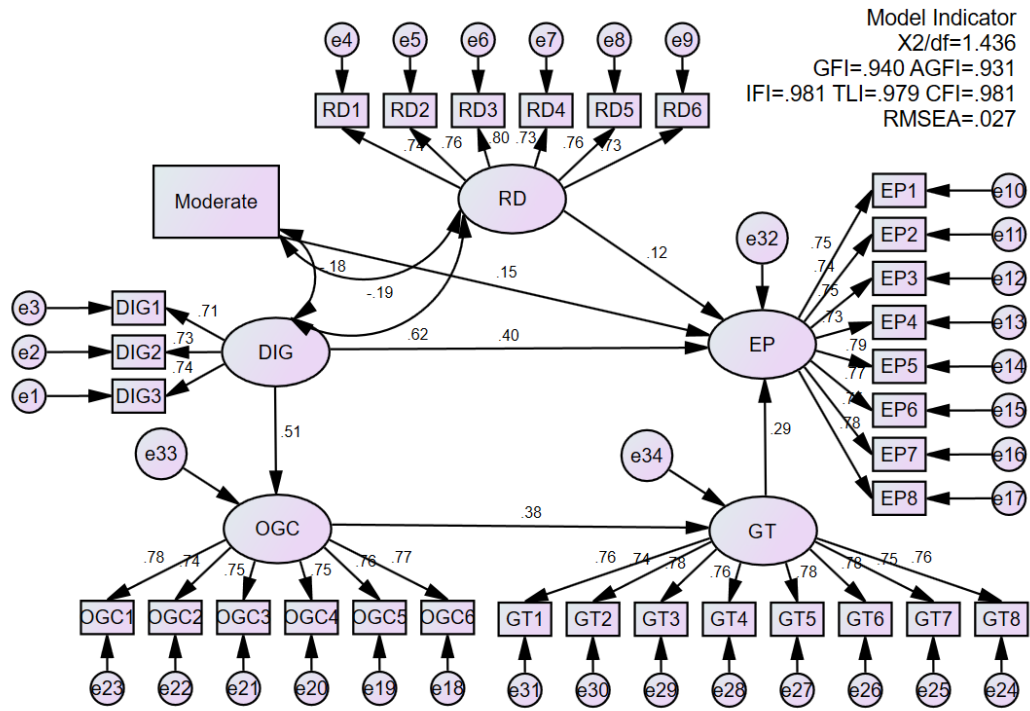


Figure 2: SEM

We used AMOS to get the path coefficient and the result shows in figure SEM. The Chi square test $\chi^2/df = 1.436$, it is smaller than 3, Root Mean Square error of approximation (RMSEA) = 0.027, Comparative Fit Index CFI = 0.940, NFI = 0.940, Adjusted Goodness of Fit Index (AGFI) = 0.931, PGFI = 0.812, PNFI = 0.865. This model fits the data well and it offers support for reliability and validity analysis.

	Estimate	S.E.	C.R.	P-value	Hypothesis
DIG->OGC	0.584	0.058	10.04	***	Supported
OGC->GT	0.382	0.046	8.366	***	Supported
DIG->EP	0.459	0.07	6.531	***	Supported
GT->EP	0.287	0.04	7.12	***	Supported
R&D->EP	0.123	0.054	2.285	0.022	Supported
Interaction->EP	0.148	0.036	4.077	***	Supported

Note(s): *** means $p < 0.1\%$

Table4: SEM Estimates

Table4 shows that the correlation of DIG and OGC, OGC and GT, DIG and EP, GT and EP, Interaction and EP are significant with a p-value smaller than 0.1%. The relationship

between R&D and EP is also significant, but the p-value is 0.022. All the hypotheses we mentioned are proved. The estimated value of R&D and interaction item are smaller than others. So, we can find that there are moderating effects, but it is weak.

3.5 Testing of hypothesized relationships

The structure of our model includes mediator and moderator. The mediator aims to explain the reason. People assumed that the mediator have a position between independent variable and dependent variable(Rasoolimanesh et al., 2021).

3.5.1 Mediator

We used the SPSS to check the mediator shows in Table 5. The mediator must have significant correlation with both independent variable and dependent variable. And when the mediator joins in the impact of independent variable on dependent variable become weaker(Baron and Kenny, 1986). In this study we tested the correlation among digitalization, organizational green culture and green transformation in hypothesis 5. And hypothesis 7 including organizational green culture and green transformation and environmental performance is also tested. To know if OGC and GT are the mediator in the model, we also analyzed the mediator effect of these variables.

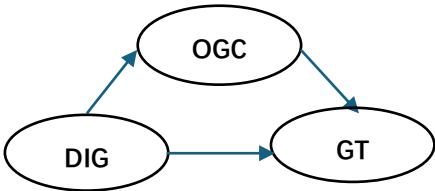
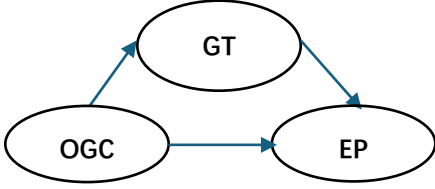
Hypothesis	Pictorial view	SEM results		
		Path	β	P
Hypothesis 5	 <pre> graph LR DIG((DIG)) --> OGC((OGC)) OGC --> GT((GT)) DIG --> GT </pre>	DIG-GT	0.470	0.000
		DIG-OGC-GT	0.392	0.000
Hypothesis 7	 <pre> graph LR OGC((OGC)) --> GT((GT)) GT --> EP((EP)) OGC --> EP </pre>	OGC-EP	0.356	0.000
		OGC-GT-EP	0.226	0.000

Table5: Mediation (SEM)

In hypothesis 5, the correlation between digitalization (DIG) and green

transformation (GT) is significant. When Organizational green culture (OGC) participates in the relationship, coefficient between DIG and GT became smaller. it means that the influence of DIG on GT get weaker because of joining of OGC. So OGC is a mediator of DIG and GT.

Similarly, in hypothesis 7, the value of β is smaller for the participation of GT in the effect of OGC on EP. And the correlations among the three variables are significant. We considered that GT is a mediator between OGC and EP.

3.5.2 Moderator

We used the SPSS Process to test the moderator. The moderator can affect the independent variable and dependent variable. It can make the correlation between independent variables and dependent variables become weaker and change the correlation to positive or negative(Söderlund, 2023a).

Variables	β	P
DIG	0.470	0.000
DIG	0.339	0.000
R&D	0.270	0.000
DIG	0.356	0.000
R&D	0.289	0.000
Interaction term	0.152	0.000

Table6: Moderator

We did the moderator test in this research in Table 6. The coefficient of the relationship between DIG and EP is 0.470 and it is significant. When the R&D joined in the regression, the coefficient fell to 0.339. The interaction term related to DIG and R&D. After the interaction term was tested, the coefficient of DIG became 0.356. It is lower than the beginning and still significant. The interaction term's coefficient is 0.152 which is positive and significant. It shows that there are moderating effects in this model.

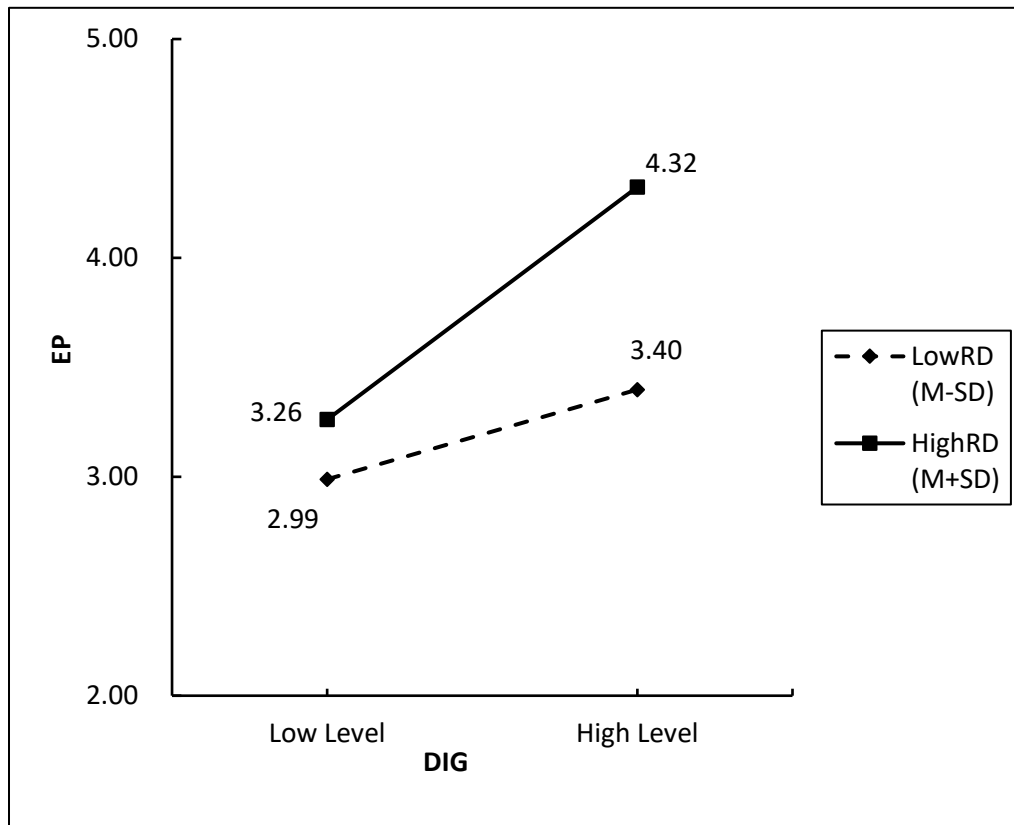


Figure 3: Moderator effect

This Moderator effect figure shows the changing trend of DIG and R&D. The slope of high R&D is larger than the line of low R&D. When the R&D level is low, DIG has a weaker influence on EP. When the R&D level is high, DIG has a stronger influence on EP. So, R&D has moderating effects between DIG and EP and the effects are positive.

4 Discussion

The p-value of correlation among five variables is smaller than 0.05. All the five variables have positive and significant correlations. OGC is the mediator between DIG and GT. GT is the mediator between OGC and EP. So OGC and GT are the mediator between DIG and EP. The DIG can affect EP through OGC and GT. So, hypothesis 5 and hypothesis 7 is proved. R&D has moderator effect between DIG and EP. When R&D level is higher the effect of DIG level on EP becomes lower. When R&D level is lower the effect of DIG level on EP is higher.

Our research found that digitalization level can positively affected the organizational green culture. The digital technology and social culture is more and more

complicated impacted by each other(Grover et al., 2022). The digitalization level in SMEs influences their environment performance through organizational green culture and green transformation. A company with high digitalization level is more likely to grow their culture using environmentally friendly thoughts. This culture affects both managers and ordinary staff's behaviors to focus on environment protection and prompt companies' green transformation. Being responsible to the society, for example using clean energy, owning environmental protection certification can receive reward in environmental performance. The company's reputation for the environment has improved. Research and development positively moderate digitalization and environmental performance. R&D strengthens the influence of digitalization on environmental performance.

It is different from the research of digital transformation and environmental performance. In that research they considered that green culture can strengthen the correlation of digital transformation, green capability and environmental performance. The green culture has a moderator effect between digital transformation and environmental performance (L. Li & Lin, 2024). The relationship between digitalization and environmental performance is a u-shaped curve. They have a negative relationship at the beginning and become positive later. In their research, their correlation is moderated by education level(Yang et al., 2023c). It may be because that they collected data in the textile industry in China, most of these industries have a low digitalization level. At the beginning, it is hard for them to increase the digital level and it will increase the cost of the company.

In the manufacturing industry, digitalization in production especially the information and communications technology (ICT) can reduce the chemical oxygen demand emission and it is similar to our research result(Wen et al., 2021b).

Companies can use our research as a guideless when they want to improve the environmental performance including company's social reputation and waste reduction. Our study shows that enterprises can develop their environmental performance by improving the use of digital production and logistics, digital value chain and big data. They can also put green thoughts in their culture, get environment certifications and

Implement energy conservation. Improving the capability of doing research and getting development can strengthen the effect if the company wants to increase their environmental performance by digital transformation.

5 Conclusion and future research

Digitalization can improve the companies' environmental performance. Research and development can moderate DIG and EP. And there is another way that DIG can affect the EP through adjusting the green culture in the company to influence green transformation. There are still some limitations in our research. We only collected data in China. Chinese manufacturing industry is leading the world(Wen et al., 2022). So, the developing of digitalization in China might be easier than places not that developed in digital technology. The limitation of region may cause a difference in results. Similarly, different industries have different developing in digitalization level. As we mentioned before, the textile industry needs to spend more to build the digital system, because their original digitalization level is low. So, we need to consider the different situation in different industries. Therefore, in our research, R&D and DIG have a significant positive correlation. It should be considered as a quasi-moderator(Söderlund, 2023b). It means that R&D can directly affect the DIG. The moderate effect might be unclear because of the correlation between R&D and DIG.

We only know that DIG positively affects the EP in the industries. But we are still not sure what specific aspects can improve the DIG level. Which kind of digitalization can be a crucial factor in environmental protection is still not clear. And about how to combine the company's culture and green awareness is also should be explored. If the influence of ordinary and general staff is larger than the managers since the number of common staffs is larger. Or maybe leaders impact the companies' awareness more because they set the rules in the companies. And what types of awareness should be included in a company's culture is also not solved.

Continuing to discuss if R&D is a moderator is also necessary since the independent variable and moderator have a significant correlation in this research. We should figure out is there any way to avoid the impact of R&D on DIG.

In our research, our object of study is SMEs. We found that digitalization can

improve environmental performance. But for the SMEs, they may not have enough budget to improve their digitalization level. How to overcome the limitation of SMEs' resources is another problem. There are researches that shows that the correlation between DIG and EP is a U shaped curve(Yang et al., 2023c). At the beginning, firms need to spend a lot to improve their digitalization level. For SMEs, they might not have enough resources to spend on DIG. And some firms may not be willing to spend money on improving DIG even if they want to develop EP because of their negative correlation at the beginning. So, in future research, people should discuss if there are some detailed ways for SMEs to develop their digitalization level. Figuring out how to increase the use of digital technology at a low cost is also benefit for the environment.

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Questionnaire

1=Strongly Disagree, 2=Moderately Disagree, 3=Neutral, 4=Moderately Agree, 5=Strongly Agree

1=非常不同意, 2=一般不同意, 3=中立, 4=一般同意, 5=非常同意

Digitalization(Radicic & Petković, 2023) 数字化

Q1. Digital production and logistics 数字化生产与物流

Your enterprise currently uses digital interconnection within production/provision of services or digital interconnection between production/service provision and logistics in a high level. 您的企业目前在生产/服务提供中使用数字互联, 或者在生产/服务提供和物流之间使用数字互联。

Q2. Digital value chain 数字价值链

Your enterprise currently uses digital interconnection with customers or digital interconnection with suppliers in a high level. 您的企业目前在高水平上使用与客户或供应商的数字互联。

Q3. Big data 大数据

Your enterprise currently uses big data analysis in a high level. 您的企业目前在较高层次上使用大数据分析。

R&D 研究和发展

Q4. Your enterprise conduct in-house R&D activities during 2014 to 2024. 贵公司在 2014 年至 2024 年期间进行内部研发活动。

Green Transformation(Feng et al., 2024) 绿色转型

Q5. My enterprise has environmental welfare activities. 我的企业有环保福利活动。

Q6. My enterprise receives environmental recognition. 我的企业受到环保的认可。

Q7. My enterprise was not punished for environmental protection. 我的企业没有因为环境保护而受到过惩罚。

Q8. The company has ISO Environmental management system certification. 公司拥有 ISO 环境管理体系认证。

Q9. My company discloses the social responsibility report. 我所在的公司披露了社会责任报告。

Q10. My company uses treatment of “three wastes” pollutants. 我所在的公司采用“三废”污染物处理。

Q11. The company implements energy conservation. 公司实行节能。

Q12. The company Implement cleaner production. 公司实行清洁生产。

Environment Performance(Aggarwal & Agarwala, 2023c) 环境效绩

Q13. In my organization, environmental management efforts have significantly reduced waste within the production process. 在我的组织中，环境管理的努力已经大大减少了生产过程中的浪费。

Q14. In my organization, environmental management efforts have significantly improved product quality. 在我的组织中，环境管理的努力大大提高了产品质量。

Q15. Focusing on environmental management has enhanced the reputation of my organization. 注重环境管理提高了本组织的声誉。

Q16. In my organization, the benefits of environmental efforts have outweighed the costs. 在我的组织中，环保工作的收益大于成本。

Q17. My organization's environmental efforts have led to improved organization's performance. 本组织在环境方面的努力已经改善了本组织的绩效。

Q18. The environmental efforts of my organization have caused us to investigate alternate technologies and procedures. 本组织在环境方面的努力促使我们研究替代技术和程序。

Q19. My organization has reduced its water and energy consumption. 我的组织已经减少了水和能源的消耗。

Q20. My organization has reduced the purchases of nonrenewable materials, chemicals and components. 我的组织已经减少了不可再生材料、化学品和部件的购买。

Organization green culture(C.-H. Wang, 2019) 组织绿色文化

Q21. Our firm makes a concerted effort to make every employee understand the importance of environmental preservation. 我们公司努力使每一位员工都认识到保护环境的重要性。

Q22. Our firm has a clear policy statement urging environmental awareness in every area. 我们公司有一个明确的政策声明，以敦促在每个领域的环保意识。

Q23. Environmental preservation is a high priority activity in our firm. 保护环境是我们公司的首要任务。

Q24. Preserving the environment is a central corporate value in our firm. 保护环境是我们公司的核心价值观。

Q25. Our firm links environmental objectives with our other corporate goals. 我们公司把环境目标与其他公司目标联系起来。

Q26. Our firm develops products and processes that minimize environmental impact. 我们公司开发的产品和工艺尽量减小对环境的影响。