An Analysis On The Dynamic Effect of Enterprise's Environmental Governance On Green Technology Innovation: New Explanation From The Perspective of Knowledge And Technology Transfer

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25
26 **Abstract:** Environmental governance (*EG*) and green technology innovation (*GTI*) are
27 important means to promote the construction of ecological civilization of all countries
28 around the world. Past scholars focused on the impact of *EG* on *GTI* based on the static
29 perspective usually, but ignored the impact of the dynamic development law of
30 enterprises. This study differentiates, takes enterprise's life cycle stage as the
31 breakthrough point, and analyzes the dynamic effect of *EG* on *GTI* at the first time.
32 Further, considering the important of information interaction among different enterprise
33 in the background of collaborative innovation, this study reveals the evolution trend of
34 enterprise's knowledge and technology transfer (*KTT*) in different life cycle stage, and
35 explains the internal mechanism of the dynamic effect mentioned above. The theoretical
36 model finds that for enterprises in different life cycle stage, the impact of *EG* on *GTI*
37 depends on abatement cost and innovation compensation effect two aspects. The
38 development of enterprise's *KTT* helps to strengthen the incentive effect of *EG* on *GTI*,
39 thus causing the differentiated *GTI* effect among different enterprises under the restrict
40 of *EG*. The empirical research results based on the micro data of Shanghai and
41 Shenzheng A-share listed firms from 2013 to 2018 in China confirm the theoretical
42 inference. *EG* has a positive role in promoting *GTI*, however, compared with the

enterprises in growth and mature stage, the positive innovation effect does not hold for the enterprises in recession stage. The statistical results show that the enterprise's *KTT* in growth and mature stage is significantly better than that of enterprises in recession. Moreover, the empirical analysis results confirm that enterprise's *KTT* have a positive moderating effect on the relationship between *EG* and *GTI*. Combined with the above conclusions, this study puts forward several useful management implications for improving the designing of environmental governance system, optimizing the cooperation of *GTI* and the *EG* decision-making under the background of collaborative innovation.

Key words: Environmental Governance; Knowledge and Technology Transfer; Green Technology Innovation; Life Cycle; Dynamic Effect

1. Introduction

Due to the deviation between traditional economic model characterized by environment resource consumption and social needs of sustainable economic development, environmental governance (*EG*) is one of the major direction for the further development of global economy (Zhang et al.2020). However, influenced the public nature of environmental pollution, market mechanisms are hard to fully correct the economic development direction (Tong and Ze,2021; Borsatto and Bazani,2020). *EG* is the policies and measures formulated by government, which is employs price and quantity tools to adjust enterprise's environmental pollution, focus on the reducing of the dis-economy to the optimal level, and achieves the goal of sustainable development

(Zhou et al.2021; Qiu et al.2021). Since then, the governments around the world have designed and implemented scientific and rational *EG* to solve the problem of environmental pollution (Jiang et al.2018; Dong et al.2020). For example,Paris Agreement signed the *Paris Climate Conference* in 2015 and regulated the reduction of greenhouse gas emissions by all parties. In June 2018, the *State Council of China* issued the “*blue sky defensive war*”, which aims at the promoting of energy conservation and emissions reduction in the key sectors.

Different from the *EG* aimed at the terminal environmental governance, green technology innovation (*GTI*) is an important starting point for the enterprises to win the battle of pollution control and ecological civilization construction (Wang et al.2021). Therefore, a series of green technological strategies for reducing pollution that produced by traditional technologies must be respond to social need (Cubillos-Gonzalez and Cardoso,2020). According to Porter and Linde (1995), *GTI* are induced by the strict environmental governance measures, in order to offset compliance costs. In detail, *EG* significantly improves enterprise’s “green” consciousness, and increases the enterprise’s abatement cost thus encouraging them to invest in *GTI* (Song et al.2020).

Two basis theories explain the effect of *EG* on *GTI*. *GTI* of enterprises is restricted by *EG*, which is called the “restriction hypothesis” (Gollop and Roberts,1983). Based on the technology innovation patent data of listed companies, industries and regions, scholars used panel econometric model to verify and support the inhibition effect of *EG* on *GTI* (Feng et al.2018; Hu and Liu,2019; Qiu et al.2020; Li et al.2020). Influenced by the “organizational failure” or “market failure” (Amber et al.2010), Porter (1991)

and Porter and Linde (1995) provided the opposing view which argues that *EG* increases costs in the short term, but promotes enterprises to carry out *GTI* in the long term, thereby reducing abatement costs and ultimately enabling them to be more competitive. Since then, many scholars took the provincial, listed companies, high pollution industry and other relevant data as research object, used fixed effect model, questionnaire survey, structural equation model and panel measurement model to test the existence of "innovation compensation" effect between *EG* and *GTI* (Cai et al.2020; Raza,2020; Qiu et al.2020; Lee et al.2010; Wang et al.2020; Li et al.2019).

Further, faced with the constraints of *EG*, heterogeneous enterprises hardly to follow the coincident *GTI* path influenced by the differentiated conditions such as internal resource endowment, dynamic capacities and external policy environment (Cai et al.2020; Luo et al.2021). That is, fully considering the uncertainty and heterogeneity conditions, not all of the enterprises achieve innovation compensation effect faced with the constraints of *EG* (Borsatto and Bazani,2020; Daddi et al.2010; Chakraborty and Chaterjee,2017). Since then, employed panel econometric model, spatial regression model and so on, several scholars pointed out that the impact of *EG* on *GTI* is nonlinear and affected by the environmental governance type, pollution intensity, technology innovation process, economic scale and so on (Dong et al,2012; Pan et al.2020; Song et al.2020; Guo et al.2018; Liu and Gong,2018).

Different from the existing researches focus on the nonlinear relationship between *EG* and *GTI*, this study points out that enterprises are difficult to achieve effective *GTI* under the constraints of *EG* simply relying on the internal resources. According to the

view of knowledge heterogeneity provided by Schulze and Brojerdi (2012), this study believes that the impact of *EG* on *GTI* is influenced by the knowledge and technology transfer (*KT*). There are many literature have studied the relationship between external knowledge heterogeneity and technology innovation, but the conclusions are different. Some scholars proposed that enterprises absorb and integrate the rich and novel heterogeneous knowledge from the outside, effectively make up for the defects of internal knowledge resources and promote collaborative innovation (Srivastava and Gnyawal,2017). Moreover, external heterogeneous knowledge reduces the core rigidity and path dependence of *GTI* , and promotes enterprises to continuously reconstructs knowledge resources and achieves green innovative achievements (Alexander and Knippenberg,2017); However, parts of scholars pointed out that heterogeneous knowledge not only easily leads to internal cognitive conflict, but also increases the management cost of knowledge transaction, which is not conducive for enterprises to carry out *GTI* (De-Leeuw et al.2014). This study argues that the reason for the above contradictory conclusions is that most of the existing studies are based on the static perspective, ignored the impact of the dynamic development law of enterprises. For example, Ballard (2009) believed that heterogeneity is essentially an interactive relationship, and its value effect is different at different stages of the development stage.

Looking at the existing literature, most scholars discussed the impact of *EG* on *GTI* based on the sample of regional and industrial levels (Johnstone et al.2010; Villegas-Palacio and Coria,2010; Hattori,2017; Cai and Li,2018), which can not directly reflect the enterprise's *GTI* under the pressure of *EG*. Few literature focused on

the enterprise level (Popp,2003; Klemetsen et al.2018; Ramanathan et al.2018), but most of them took the developed countries as research objects. However, there is a substantial gap of industrial modernization and *EG* system between China and developed countries (Cai et al.2002). In addition, the heterogeneous effect of *EG* on *GTI* has not been explored, thus making the practical significance of the research results needs to be improved. Knowledge-based theory holds that external heterogeneous knowledge fills in the knowledge gap of enterprises, while internal knowledge diversification will affect the meaning construction and interpretation results (Oerlemans et al.2013;Secchi et al.2016). Previous studies have shown that knowledge diversification expands its own knowledge base, explores a variety of innovative combinations with the acquired external heterogeneous knowledge, and effectively breaks the thinking bottleneck. However, there is still no relevant research takes the *KT* as the starting point, explain the formation mechanism of the dynamic effect of *EG* on *GTI* from the perspective of life cycle stage.

Compared with the existing researches, the possible contributions of this study include the following two aspects: First, although existing studies have carried out specific analysis of the effects of *EG* on *GTI* on industry and regional levels, seldom use data at the micro-level. Considering enterprises as the main body of *EG* and *GTI*, analyzing the effect of *EG* on *GTI* from the micro level of enterprises is a complement to existing researches; Second, the *KT* of enterprises in different life cycle stages is an important factor to regulate the *GTI* under the constraints of *EG*. Existing research does not discuss the non-linear relationship between *EG* and *GTI* from this perspective. This

study dynamically analyzes the impact of *EG* on enterprise's *GTI* in different life cycle stages, and expounds the formation mechanism of dynamic effect mentioned above from the perspective of *KTT* at the first time.

2. Theoretical analysis and research hypothesis

According to the research of Montero (2002), this study considers a model which includes two profit-maximizing firms. Firm i produces q_i at cost c , and the inverse demand function is $P = P(Q)$, where P is the market price and $Q = q_1 + q_2$ is industry output. In the absence of *EG*, enterprises produce q_i units of emission, and the cost of q_i is $C_i(q_i - e_i)$, e_i is the final emissions after abatement. As usual, $C' > 0$ and $C'' > 0$.

The aims of *EG* is to control emissions at $\bar{e} = e_1 + e_2$. Under the restriction of *EG*, firm i improve its technology of abatement by investing in *GTI*. Referring to the setting of Montero (2002), if it invests K_i , abatement costs are expected to be reduced from $\frac{r^2}{2}$ to $\frac{kr^2}{2}$, where $r_i = q_i - e_i$. According to the production function:

$$k_i = f_i(K_i, s)$$

where, $f(0) = 1, f(\infty) > 0, f' < 0, f^* > 0$ and $f'' > 0$.

Assumes that the difference between firm 1 and firm 2 is that enterprise 2 does not carry out *GTI* under the restrict of *EG*, but bears the penalty cost A due to violation of *EG*. Further, based on the *KTT*, the investment of *GTI* changes form $\frac{K^2}{2}$ to $(1-s)\frac{K^2}{2}$. s is the parameter of firm's *KTT*. Then the profit functions of firm 1 and firm 2 can be expressed as:

$$\pi_1 = [a - b(q_1 + q_2) - c]q_1 - (1-s)\left(\frac{kr^2}{2} + \frac{K^2}{2}\right) \quad (1)$$

$$\pi_2 = [a - b(q_1 + q_2) - c]q_2 - A \quad (2)$$

$$s.t. \quad mq_1 - r = \bar{e} \quad (3)$$

where, m is the pollutant generation coefficient, which represents the proportion of the firm's pollutant production in the product output. Therefore, mq_1 represents the pollutant production of firm 1, and $\bar{e}$ represents the firm's maximum pollutant emission specified by the government. Therefore, the economic meaning of equation (3) is that the emission of firm 1 is equal to the scale which regulated by the government EG . According to the first-order condition of profit maximization under constraint conditions, obtain partial derivatives of output q_1 and q_2 , emission reduction r and Lagrange multiplier λ :

$$\frac{\partial \pi_1}{\partial q_1} = a - 2bq_1 - bq_2 - c - \lambda m = 0 \quad (4)$$

$$\frac{\partial \pi_2}{\partial q_2} = a - bq_1 - 2bq_2 - c = 0 \quad (5)$$

$$\frac{\partial \pi_1}{\partial r} = -kr + \lambda = 0$$

$$(6)$$

$$\frac{\partial \pi_1}{\partial \lambda} = mq_1 - r - \bar{e} = 0 \quad (7)$$

Based on the equation (6), obtain $\lambda = kr$ and substitute to equation (4)

$$\frac{\partial \pi_1}{\partial q_1} = a - 2bq_1 - bq_2 - c - krm = 0 \quad (8)$$

Based on equation (5) and (8), obtain q_1 and q_2 :

$$q_1 = \frac{a - 2krm - c}{3b} \quad (9)$$

$$q_2 = \frac{a + krm - c}{3b} \quad (10)$$

Substitute q_1 and q_2 to equation (1) and (2), the profit of firms are subtracted to obtain:

$$\Delta \pi = \pi_1 - \pi_2 = A - \frac{(a + krm - c)krm}{3b} - (1-s)\frac{kr^2}{2} - (1-s)\frac{K^2}{2} \quad (11)$$

where, $\Delta\pi$ is determined by the government's penalty cost A , firm's GTI capability k , abatement costs $\frac{kr^2}{2}$, GTI costs $\frac{K^2}{2}$ and KTT parameter. It means that when the marginal profit greater than zero after the introduction of EG , enterprises will have enough incentive to carry out GTI .

Based on the equation (11), abatement costs $\frac{kr^2}{2}$ represents the investment in purchasing of clean equipment and hiring technical staff, which can be regarded as the firm's "following the cost effect" under the constraints of governance environmental regulation (Hu and Liu,2019). If the products produced by the firms have low market demand elasticity and maintain a certain monopoly position, EG cost can be transferred to consumers by raising product price and stimulates firms to carry out GTI by obtaining excess monopoly profits (Hattori, 2017). Moreover, with the adjustment of GTI strategy, polluting enterprises faced with the constrains of EG gradually withdraw from the market. The technical barriers constructed by technological monopoly position become the monopoly profit source and an incentives mechanism for the green enterprises to carry out GTI (Melitz,2003). Finally, faced with more stringent EG , adopting GTI improves firm's clean product abilities and reduces the marginal abatement cost on the basis of keeping the original output unchanged, thus stimulating firm's GTI intentions (Xia et al.,2021). Therefore, this study puts forward the Hypothesis 1:

H1: EG has a positive effect on GTI .

EG is difficult to achieve by firms lonely, which needs multi-agent coordination and agglomeration of innovation elements (Schubert and Gupta, 2013). In order to meet the social environmental need, enterprises combine related topics through various forms

of collaborative innovation, expand the innovation network, absorb innovation elements, form technology collaboration, tackle common problems in the process of *EG*, and reduce the cost of abatement costs $\frac{kr^2}{2}$ (Kim and Sim, 2016; Zhang et al., 2020). Under the pressure of *EG*, *GTI* in an environmental management requires new ways of thinking and applies it throughout *EG* (OECD, 2012). It is a kind of creative ideas generated from individuals or staff, and occur with support from R&D and through knowledge and technology transfer (Cubillos-Gonzalez and Cardoso, 2020; Gu et al., 2021). In the process mentioned above, *KTT* is helpful to expand the scope of enterprise's search resources, help enterprises identify and obtain the technology required for *EG*, realize the coordination of external and internal technology sources, promote the evolution of *GTI* ability, and quickly reduce the cost of *GTI* denoted by $\frac{K^2}{2}$ (Liu, 2019). Therefore, this study puts forward the Hypothesis 2:

H2: The *KTT* positive moderate the impact of *EG* on *GTI*.

3. Model and data

3.1 The benchmark regression model

The main concern of this study is whether *EG* can promote *GTI*. Due to the measurement of *GTI* is the number of applications for environmental patents, so, this paper constructs the following panel counting model.

$$GTI_{i,t} = \alpha_0 + \alpha_1 EG_{i,t} + \sum_{j=1}^8 a_j X_{j,i,t} + \nu_i + \varepsilon_{i,t} \quad (12)$$

where, the subscripts *i* and *t* denotes the firm and year, respectively. *GTI* indicates the level of firm's green technology innovation, *EG* represents the environmental

governance. X represents the control variables, mainly includes the age of enterprises, the current ratio, the return on assets, the turnover rate of assets and the enterprise ownership structure. ε is a random error term, v_i is individual effect, and α_i are all parameters to be evaluated. In order to alleviate the endogeneous problem caused by the relationship between EG and GTI , this study adopts the fixed effect model to allow v_i to be correlated with the explanatory variable(Cai et al.,2020).

3.2 The moderating effect model

In addition to the direct impact of the EG on the GTI , KTT also indirectly moderate the relationship between the EG and the GTI . The cross-term method of the KTT and EG is introduced to investigate the moderating effect of KTT , and the corresponding model is presented:

$$GTI_{i,t} = \alpha_0 + \alpha_1 EG_{i,t} + \alpha_2 EG_{i,t} * KTT_{i,t} + \sum_{j=1}^8 a_j X_{j,i,t} + v_i + \varepsilon_{i,t} \quad (13)$$

where, a_1 and a_2 reflect the direct and indirect effects of the EG on the GTI , respectively.

3.3 Data sources and variables description

This study collects all listed firms of Shanghai and Shenzhen A-shares in China from 2013 to 2018. Among them, GTI patents and KTT are collected from the *State Intellectual Property Office (SIPO)* of the *People's Republic of China*; EG is obtained mainly through the annual reports or social responsibility reports of listed firms; Other control variables were collected from the CSMAR Data Service Center and the Wind Financial Database. This study excludes ST and $*ST$ firms with abnormal financial status and with missing data. Finally, 795 observation samples were obtained.

Winsorize treatment was performed on the 1% level of all continuous variables. Table 1 shows the description analysis results.

3.3.1 Dependent variables

Environmental patent applications were used here as a measure of *GTI*. In order to improve the core of competitiveness of enterprises, they used to apply for patents to keep technological advantages, so as to obtain greater profits. In addition, the authorization of the invention patents through the strict examination of the patent examiner, they has a stronger practicability, novelty, and creativity (Klemetsen et al.2018). Therefore, *GTI* is measured by the patent applications for environmental inventions. Combined with the IPC classification issued by the *World Intellectual Property Organization (WIPO)*, this paper took alternative energy production, waste management, energy conservation as the specific items, matched the number of environmental patent applications filed by each listed firms in the *SIPO* database.

3.3.2 Independent variables

Past researches usually used the different indicators, such as the rectification of violations and administrative penalties for environmental protection as the indicator of *EG*. According to the research of Song and Wang (2020), this study takes pollution treatment investment of enterprises as an indicator of *EG*, it refers to the capital used to form fixed assets in the process of pollution treatment, which includes the investment in environmental infrastructure construction, new and old pollution sources control projects and environmental protection investment projects.

Age of the enterprises: according to the year of establishment, enterprise's *GTI* is

significantly improved with their rapid development, while reduced when enterprises enter the stage of recession (Balasubramanian and Lee, 2008).

The return on assets is the percentage of a company's profit divided by its net assets, which reflects the ability to obtain income based on its own assets (Xin et al.,2010). The growth of return on assets can enhance the financial support for green investment and promote *GTI*.

The Current ratio is the ratio of current assets to current liabilities, which reflects the ability of current assets to be realized and used to repay liabilities. The higher the value is, the stronger the short-term solvency is, which is helpful to increase *GTI* investment, otherwise it is weak.

Ownership structure: The main reason for the lack of motivation or efficiency of *GTI* in state-owned enterprises is that there is a serious principal-agent problem, which can not effectively supervise and motivate the operators (Boubakri et al.,2013). However, state-owned enterprises have obvious advantages over private enterprises in obtaining innovation resources (Wang et al.,2017).

Asset turnover rate: it is an index to evaluate the efficiency of a company's asset operation and reflects the utilization efficiency of the company's assets (Ang, 2000). The higher the asset turnover rate of an enterprise, the stronger its sales ability, the higher the efficiency of asset utilization, and the lower the principal-agent cost.

3.3.3 Moderating variables

Innovations are creative ideas generated from individuals or staff, and occur with support from R&D and through *KT* (Muduli et al.,2013). Drivers for *GTI* include

strong business networks, seeking to build competitive advantage, R&D organizational support, cost savings, subsidies and tax cuts, compliance with regulations and customer demand (Vasilenko and Arbaciauskas,2012). *KTT* reflects the information interaction among enterprises by means of technology transfer and patent disclosure (Claro et al.,2006). According to the research of Hastbacka(2004), West and Gallagher (2006), this study measures the *KTT* by the enterprises "Whether there is a technology disclosure/transfer" and "whether there is a patent disclosure /transfer", where "yes" is 1 and "no" is 0.

Insert Table 1 here

4. Results and discussion

The value of *VIF* is much lower than 10, and indicates that there was no problem with multicollinearity. The results of correlation analysis listed in the Table 2 shows that the correlation coefficient of each variable is less than 0.7.

Insert Table 2 here

4.1 The benchmark effect of EG on GTI

Based on the equation (12) and employed the static fixed effect model, the benchmark effect of *EG* on *GTI* is tested. As can be observed from the results listed in the second column of the Table 3, the coefficient of *EG* is 0.05 and passes the significance test at 1% level. In order to guarantee the reliability of the empirical results, each control variables are added step by step. As shown in columns from (3) to (7) of

Table 3, the regression coefficients of *EG* varied from 0.077 to 0.094 and pass the significance test at 1% level. According to the the theory of institutional economy, *EG* has the function of influencing and constraining organizational behavior (Li et al. 2017). Lower *EG* is hardly to affect the enterprise production and management activities and the decision-makers in the system pressure (Chen and Zhang, 2017). With the improvement of regulator standards, the production suspension and production restriction directly affect the decisions of *GTI* (Wang and Li, 2009; Guo and Licheng, 2020).

4.2 Endogenous recognition and system generalized method of moments (System-GMM)

The impact of *EG* on *GTI* may be endogenous, which leads to inconsistent estimates. There are two main reasons for this: (1) Simultaneous equations endogenous: the enterprises who investment in *EG* will pay more attention on *GTI*. However, *GTI* further reduces the enterprise's pollution control investment, which leads to non-exogenous of *EG*. The endogenous of simultaneous equations caused by the interaction can be eliminated by substituting the explanatory variables with their lag term. (2) Missing variable endogenous: even though the control variables are considered as comprehensively as possible, there are many other factors related to the *GTI* can not be expressed quantitatively, such as entrepreneurship, development strategy, etc. The solution is to add the one-period lag term of *GTI* as an explanatory variable.

According to the research of Arellano and Bover (1995) and Blundell and Bond (1998), the System-GMM model is employed to estimate the results. As shown in the Table 4, the regression coefficients of *L. EG* and *L. GTI* is 0.057 and 0.616, respectively,

both of them passes the significance test at 1% level. It must be noted that the above conclusion is based on the premise that GMM estimates are effective. The AR (1) , AR (2) and Sagan test statistics reported in Table 4, which proved that the tool variables selected in system-GMM estimation are valid.

Insert Table 3 here

4.3 Analysis of the heterogeneity of enterprise's life cycle

As a highly uncertain and risky economic behavior, *GTI* has a vital impact on its own heterogeneous resources and unique capabilities. In reality, different enterprises consider internal and external conditions comprehensively, and will adopt a differentiated behavior-oriented mode to deal with environmental pollution problems, it means that promoting the efficient matching between *GTI* decisions and capability is the key link under the constraints of *EG* (Luo et al.2021). Thus, from the perspective of enterprise life cycle stage, this study examines the heterogeneity effect of *EG* on *GTI*.

Using different enterprise life cycle stage division criteria will get different results. The mainstream method of classification mainly including comprehensive scoring and cash flow classification (Anthony and Ramesh,1992). Compared to the comprehensive scoring method, the cash flow-based stage division method effectively avoids the possible linear relationship among indicators, and overcomes the bias caused by the enterprise managers earnings manipulation (Dickkinson,2011). Therefore, this study uses the characteristics of enterprise cash flow to divide the life cycle stage. Considering that the sample data in this study are listed firms and have basically passed the initial

stage. According to the criteria proposed by Dickinson,(2011), the sample enterprises are divided into three stages: growth, mature and recession.

The heterogeneity regression results are shown in the Table 4. Compared with the regression coefficients of *EG* in different life cycle stages, it can be found that the effect of *EG* on *GTI* in mature stage is the most significant (0.089), it is relatively weak in growth stage (0.053), while, the effect is insignificant in the recession period. The view of natural resource-based is helpful to explain the relationship between firms' life cycle state and the *GTI* under the restrict of *EG* (Hart, 1995). Firms invest in environmental strategies under the pressure of *EG*, such as *GTI*, will be able to keep economic growth (Ashraf et al.,2018). Firms want to obtain greater advantage and be motivated by future benefits, are more likely to invest in *GTI* (Ashraf et al.,2018). In addition, firms that consider the natural environment are better able to utilize their resources and capabilities when adopting *GTI* (Adeel et al.,2020).

Insert Table 4 here

4.3 Analysis of the moderating effect of KTT on the relationship between EG and GTI

Based on the previous analysis, we find that *EG* has different effects on *GTI* of enterprises in different life cycles. Combined with theoretical analysis, *KTT* has a significant moderating effect on the relationship between *EG* and *GTI*. In order to verify the above inference, we carries out the quantitative analysis on the life cycle difference and its moderating effect of *KTT*.

According to the research of Gao et al.(2011), we test the difference of enterprise's

KTT in different life cycle stage by one way test of variance . The p value of Bartlett test is less than 0.05, which means that F test is significant at 5% level. That is, the *KTT* of enterprises in different life cycle stages is different. Further, it can be seen from the Figure 1, compared with the enterprises in the recession period, the *KTT* scale of enterprises in the mature and growth periods is larger.

As shown in the Table 5, the coefficient of $EG*KTT$ is positive and pass the significance test at the 1% level, it means that the *KTT* has a positive moderating effect on the relationship between *EG* and *GTI*, thus validating the rational of hypothesis H2, which posits that compared with the enterprises with lower *KTT* scale, the promotion effect of *EG* on the enterprise's *GTI* with higher *KTT* scale is more significant. This conclusion further confirms the inference in this study that *KTT* is an important determinant of the differentiated impact of *EG* on *GTI* in different life cycle stages. In addition, the estimation results based on System-GMM show the results are robust. First, growth and mature firms have stronger *KTT* networks which promote the enterprises to improve *GTI* abilities through adopting advanced technology and equipment (Tsai and Ghoshal, 1998). Moreover, stronger *KTT* capabilities facilitates the development of *GTI* and achieves higher *GTI* performance (Adeel et al.2020). Second, *KTT* enhances promotes enterprises to capture new information and improve their *GTI* efficiency. Therefore, stronger *KTT* abilities facilitate assimilation of knowledge from external sources, and it is useful to reduce the abatement costs and achieve higher *GTI* efficiency under the constraint of *EG* (Ketata et al.2014) .

Insert Figure 1 here

Insert Table 5 here

5. Conclusions and policy recommendations

Based on the micro enterprises of pollution treatment investment and green technology innovation patent applications of Shanghai and Shenzhen A-share listed firms in China from 2013 to 2018, this study employs static fixed effect model and system-GMM two model to dynamically analyses the impact of *EG* on *GTI* from the perspective of enterprise's life cycle stage. Further, this study reveals the importance of information interaction for reducing abatement costs and improving *GTI* performance, starting from the view of *KT*, explains the internal mechanism that *EG* has different effects on *GTI* of enterprises in different life cycle stage.

(1) The impact of *EG* on *GTI* depends on environmental governance cost and innovation compensation effect two aspects. In general, *EG* has a positive effect on *GTI*, but it has significant differentiated impact on *GTI* of enterprises in different life cycle. Compared with the enterprises in growth and mature stage, the positive effect mentioned above does not hold for the enterprises in recession stage.

(2) Based on the division of enterprise life cycle stage, it is found that the *KT* shows the trend of rising and decreasing with the development of enterprise. Further, *KT* has a positive moderating effect on the relationship between *EG* and *GTI*, thus making the impact of *EG* on *GTI* is significant is both of the enterprises in growth and mature stage, but it is insignificant of enterprises in recession stage. Based on our findings, we propose the following policy recommendations:

(1) Government agencies should appropriately strengthen the implementation of

EG policies, punish enterprises with negative environmental attitude, so as to encourage polluting enterprises to carry out *GTI*. However, the government should not blindly improves the regulation intensity, clarify the dynamic characteristics of the impact of *EG* on enterprise's *GTI*, fully considers the changes in the development stage of local enterprises, timely adjusts the regulation mode and strength, guides parts of green enterprises to obtain cost advantage through tax subsidies.

(2) Faced with the increasing of investment in pollution control, enterprises should fully realize the importance of *KT* in the collaborative innovation environment, share advanced environmental protection knowledge and innovative information resources, form a unified collaborative system of *EG* and *GTI*, so as to avoid the uncertainty brought by *EG* and improve the performance of *GTI*. Moreover, enterprises should establish a cost sharing mechanism, reduce the risk of collaborative innovation, promote the formation of long-term cooperative relationship, make up for the lack of internal resources.

(3) Enterprise managers should make straighten up and pay attention to the current stage of enterprise's development, systematically comb and summarize the enterprise's *GTI* strategies and the implementation of *EG* measures according to the life cycle stage characteristics. At the same time, equipping talents with market innovation ability, actively obtaining external support and seeking partners, thus strengthening the profitability of enterprises through *KT*.

Ethical Approval

Ethics approval is not required for this research.

Consent to Participate and Publish

The manuscript is approved by all authors for publication and is an original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the enclosed manuscript.

Authors Contributions

Xianhua Wu and Xiongfeng Pan: Conceptualization, Methodology, and Supervision.

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Competing Interests

There is no conflict of interest with this manuscript.

Availability of data and materials

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Table 1

Descriptive analysis (N=795)

Variables (Abbreviation)	Meaning	Mean	Std. Dev	Min	Max
Environmental governance (<i>EG</i>)	Pollution treatment investment	0.774	1.186	0.000	6.690
Green technology innovation (<i>GTI</i>)	Environmental Patent Application	7.436	3.352	- 13.816	17.532
Knowledge and Technology Transfer (<i>KTT</i>)	Technology Patent disclosure/transfer	0.502	0.500	0.000	1.000
Age of the enterprises (<i>AGE</i>)	Years of establishment	3.317	0.215	2.397	3.689
Current ratio (<i>CR</i>)	Ratio of current assets to current liabilities	4.877	0.610	2.865	7.994
Return on assets (<i>ROA</i>)	Ratio of net profit to annual average total assets	5.323	0.139	2.577	5.533
Asset turnover rate (<i>ATR</i>)	Ratio of business income to annual average total assets	4.158	0.576	1.556	5.748
Ownership structure (<i>OS</i>)	The state-owned enterprises equal to 1, otherwise equal to 0.	0.697	0.460	0.000	1.000

Table 2

Correlation analysis

Variables	<i>GTI</i>	<i>ER</i>	<i>KTT</i>	<i>AGE</i>	<i>CR</i>	<i>ROA</i>	<i>ATR</i>	<i>OS</i>
<i>GTI</i>	1.000							
<i>ER</i>	0.146***	1.000						
<i>KTT</i>	0.415***	0.069**	1.000					
<i>AGE</i>	0.008	-0.026	-0.013	1.000				
<i>CR</i>	-0.127***	-0.244***	-0.154***	0.026	1.000			
<i>ROA</i>	0.058*	0.018	0.091***	-0.003	0.213***	1.000		
<i>ATR</i>	0.121***	0.068**	0.165***	0.052	0.011	0.141***	1.000	
<i>OS</i>	0.060*	0.100***	0.121***	-0.115***	-0.174***	-0.121***	0.038	1.000

* p<0.1. ** p<0.05. *** p<0.01.

7 **Table 3**

8 Regression results of benchmark effect of the EG on GTI

Variables	Static fixed effect model							System-GMM
<i>L.GTI</i>								0.616*** (9.24)
<i>L.EG</i>								0.057*** (2.25)
<i>EG</i>	0.050*** (4.41)	0.041*** (3.73)	0.041*** (3.68)	0.085*** (3.46)	0.036*** (3.21)	0.036*** (3.25)	0.037*** (3.28)	
<i>AGE</i>			-0.246 (-1.27)	-1.442 (-1.26)	-0.233 (-1.21)	-0.228 (-1.18)	-0.233 (-1.21)	-0.456 (-0.92)
<i>CR</i>				-1.034 (-4.23)	-0.160** (-1.95)	-0.163** (-1.99)	-0.163** (-1.99)	0.088 (0.42)
<i>ROA</i>					0.893*** (3.38)	0.926*** (3.45)	0.914*** (3.40)	-0.036 (-0.14)
<i>ATR</i>						-0.055 (-0.70)	-0.046 (-0.58)	0.462* (1.87)
<i>OS</i>							-0.074 (-0.64)	0.641** (2.13)
<i>Cons</i>	0.362*** (3.89)	0.326 □0.69□	1.026 (1.41)	1.482* (1.83□	-3.024** (-1.94)	-2.933* (-1.88)	-2.812* (-1.79)	
<i>Year</i>	<i>N</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>N</i>
<i>Region</i>	<i>N</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>N</i>
<i>Industry</i>	<i>N</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>Y</i>	<i>N</i>
<i>R²</i>	0.021	0.453	0.454	0.455	0.464	0.464	0.464	
<i>Adj-R²</i>	0.020	0.335	0.336	0.336	0.346	0.345	0.345	
<i>F</i>	19.44***	3.85***	3.84***	3.83***	3.93***	3.91***	3.88***	
<i>AR(1)</i>								0.000
<i>AR(2)</i>								0.920
<i>Sargan test</i>								75.86**

9 The numbers in parentheses are t-statistic; * p<0.1. ** p<0.05. *** p<0.01.

10 **Table 4**

11 Heterogeneity regression results of *EG* on *GTI*

Variables	Growth	Mature	Recession
<i>EG</i>	0.053** (2.48)	0.089*** (3.07)	0.067 (0.67)
<i>AGE</i>	0.112 (0.32)	-0.998* (-1.74)	-1.516*** (-3.60)
<i>CR</i>	-0.112 (-0.63)	-0.723*** (-2.80)	-0.314** (-1.69)
<i>ROA</i>	0.700* (1.66)	0.232 (1.59)	0.185** (2.33)
<i>ATR</i>	-0.058 (-0.36)	0.025 (0.11)	0.326* (1.79)
<i>OS</i>	-0.208 (-0.96)	0.132 (0.35)	-0.172 (-0.72)
<i>Year</i>	Y	Y	Y
<i>Region</i>	Y	Y	Y
<i>Industry</i>	Y	Y	Y
<i>R</i> ²	0.497	0.793	0.711
<i>Adj-R</i> ²	0.235	0.638	0.591
<i>F</i>	1.90***	5.11***	5.91***

12 The numbers in parentheses are t-statistic; * p<0.1. ** p<0.05. *** p<0.01.

13 **Table 5**

14 Mediation effect result of *KTT* on the relationship between *EG* and *GTI*

Variables	Static fixed effect model		System-GMM
<i>L.GTI</i>			0.614*** (13.05)
<i>EG</i>	-0.032** (-2.49)	-0.031** (-2.24)	
<i>EG*KTT</i>	0.120*** (12.73)	0.096*** (9.15)	
<i>L.EG</i>			0.036 (1.03)
<i>L.EG*KTT</i>			0.032** (1.74)
<i>AGE</i>		-0.144 (-0.69)	0.506 (1.00)
<i>SOL</i>		-0.144* (-1.77)	0.736*** (3.75)
<i>ROA</i>		0.753*** (2.89)	-0.414*** (-2.84)
<i>ATR</i>		-0.116 (-1.36)	-0.194 (-1.08)
<i>OS</i>		-0.127 (-1.06)	-0.217 (-0.81)
<i>Year</i>	N	Y	N
<i>Region</i>	N	Y	N
<i>Industry</i>	N	Y	N
<i>R</i> ²	0.188	0.536	
<i>Adj-R</i> ²	0.186	0.422	
<i>F</i>	91.50***	4.71***	
<i>AR</i> (1)			0.089
<i>AR</i> (2)			0.509
<i>Sargan test</i>			109.86***

15 The numbers in parentheses are t-statistic; * p<0.1. ** p<0.05. *** p<0.01.

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Figure.1 Difference of the scale of *KTT* in different life cycle stage

Highlights

1. Takes enterprise's life cycle stage as the breakthrough point, this paper analyzes the dynamic effect of environment governance on green technology innovation.
2. The effect of environment governance on green technology innovation of enterprises with different life cycle is different.
3. Knowledge and technology transfer in growth and mature stage is significantly better than that of enterprises in recession
4. Knowledge and technology transfer have a positive moderating effect on the relationship between environment governance and green technology innovation.