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Platform Firm's IT Capabilities, External Informal Knowledge Governance, and Green Knowledge Integration in Low-Carbon Economy

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Platform ecosystem provides internal firms with an abundant source of green technology knowledge for sustainable development. In a low-carbon economy, green technology could be accumulated via platform, thus utilized to achieve energy conservation and emission reduction. From firm's social capital perspective, this study explores the effects of platform firm's IT capabilities and external informal knowledge governance on green knowledge integration. A theoretical model is constructed about their direct and interactive effects. Based on 372 samples of platform firms, the empirical test results show that IT capabilities have a significant positive impact on collaborative and sysematic green knowledge integration; external informal knowledge governance has a significant positive impact on socialized and collaborative green knowledge integration; and their interactive effects pose significant positive impact on socialized, collaborative, and systematic green knowledge integration.

1. Introduction

Low-carbon economy is advocated by an increasing number of countries as climate changes and environmental pollution looms. It has been one development mainstream of the world economy. EU, China, and many other economies are requiring firms to participate into the carbon reduction activities with concrete reduction goals or routines (e.g., carbon neutrality). Besides, from ecological perspective, industry 4.0 emphasizes the efficiency of resource and energy, which is driven by the harmony between economy and ecological environment via green technology innovation (e.g., 5G, AI) [1, 2]. In these contexts, firms, main carbon emitters, should assume key responsibilities of reducing carbon emission. In the last decades, various platforms are prevailing as firms are directly and indirectly linked by online transaction based on digital technology, especially in the era of industry 4.0 and globalization. They exist in various forms (e.g., e-commerce platform, smartphone platform). And they are usually initiated or created by key stone firms (e.g., Amazon, Alibaba Inc.). Platform, as a popular organization cluster, provides a key micro context for collaboration, cooperation and coevolution among those firms surrounding the key stone firms or dominator firms [3]. With aims of peak carbon dioxide by 2030 and carbon neutrality by 2060 committed by Chinese government, Chinese platform firms have developed rapidly in recent years. These platform firms are associated and coordinated by surrounding customer value, introducing platform ecological effects that could complement each other. The symbiosis environment in platform ecosystem provides good external conditions and abundant resources for innovation and sustainable development by searching, sharing, integrating, and creating technical knowledge inside and outside the internal firms [4, 5]. Green technology knowledge integration helps firms integrate green technology into the link of opportunity identification and innovation, thereby promotes energy conservation, emission reduction, and low-carbon development [6].

In green knowledge integration (GKI) of platform firm, many factors (e.g., knowledge characteristics, market mechanism failure) will affect technological innovation [7]. For example, the deeper the tacitness and embedding of knowledge, the more difficult its observation, which will affect the knowledge sharing, dissemination, and absorption among different platform firms. And information asymmetry, sharing dilemma, and evaluation difficulties also hinder knowledge exchange and collaboration. These problems will lead to knowledge hiding, "free riding", and other risks, so GKI should be conducted from the perspective of governance [8, 9]. In platform ecosystem, firms are linked via symbiosis. Due to the lack of formal mechanism (e.g., bureaucracy), platform firm's external informal knowledge governance (EIKG) is needed to guide green knowledge activities [10]. Different from internal informal governance tools or methods (e.g., corporate culture, personal relationship), firm's external knowledge governance primarily relies on organizational relationship, external network structure, etc. [11, 12]; however, existing studies on knowledge governance mainly focus on firm's internal teams or departments, and external firm's EKG still needs further exploration.

In platform ecosystem, low-carbon economy requires efficient coordination among platform firms. This process is accompanied by information circulation (e.g., data, knowledge), which is inseparable from information technology. Therefore, platform firm's IT capabilities (ITC) are key elements to improve the level of green knowledge management [13]. In low-carbon economy, environmental capacity is limited and environmental awareness is constantly increasing. Thus, platform firms would utilize information technologies (e.g., cloud computing, AI) to acquire more green knowledge and improve the efficiency of green knowledge creation and application. In firm's knowledge activities, ITC could promote knowledge sharing by providing data processing system and knowledge sharing platform [14]. However, the relationship between ITC and GKI needs further exploration especially in the context of platform ecosystem, such as effects of ITC on GKI and EIKG on GKI in the platform.

To explore these effects in platform firms, this study introduces social capital into firm's EIKG, constructs a conceptual model about these effects, collects 372 sample data of platform firms from China, and verifies their relationships through statistical analysis. This paper makes the following main contributions:

(1) To explore the effects of platform firm's ITC on the subdimensions of GKI and verify these effects

(2) To explore the effects of platform firm's EIKG on the subdimensions of GKI from firm's social capital perspective and discover the different roles of EIKG in the subdimensions of GKI

(3) To explore the interactive effects of platform firm's ITC and EIKG on the subdimensions of GKI, verify these effects, and analyze the moderating effects in the interaction

The rest of the paper is organized as follows. Section 2 briefly reviews the relevant literature and introduces the conceptual model. Section 3 describes the methodology used for data collection and measurement. Section 4 presents model test and analysis. Section 5 summarizes the conclusion and presents possible future work.

2. Literature Review and Concept Model Construction

2.1. Platform Firm's IT Capabilities and Green Knowledge Integration. Platform ecosystem is a super-organization composed of interrelated groups of organizations that share common vision and achieve coevolution and sustainable development through cooperative innovation [15]. It emphasizes symbiosis and openness, and provides environmental support for open innovation and low-carbon development [16]. In low-carbon economy, relying on various symbiotic relationships in platform ecosystem (e.g., mutualism, commensalism, and parasitism symbiosis), firms could achieve low-carbon-related technology and knowledge sharing, complementation, optimization, and collaboration with other members, then green technology knowledge integration and application to achieve energy conservation and emission reduction. Therefore, the efficiency of green technology knowledge activities would not only affect platform firm's green technology innovation and competitive advantages but also affect the energy conservation and emission reduction of the entire platform ecosystem.

Green knowledge is judged from its long-term positive impact on environment, and generally includes green technologies and shared vision that could protect the environment and promote firm's sustainable development [17]. Usually, platform firm's external green technology knowledge is mainly from active sharing, mutual beneficial exchange, or transaction among internal firms of the platform ecosystem, which is produced in the process of firm allying and common business transaction. In addition, core firm could enrich green knowledge of the platform ecosystem by attracting firms with complementary knowledge to join and actively promote their knowledge sharing and exchange. Noncore firm (e.g., dominator and niche firms) will actively participate in the knowledge activities to obtain environment-friendly knowledge [18]. Because of the strong complementarity of platform firms' knowledge and the small green knowledge distance, it is easy for platform firms to share and integrate their green knowledge under the symbiosis vision and the leadership of core firms in platform ecosystem.

Green knowledge integration (GKI) refers to the dynamic identification, collection, reconstruction, and optimization of green knowledge by firms, so that green knowledge could be systematically linked and integrated, which is conducive to knowledge creation and innovation [19]. It involves changes about knowledge forms, organization, and transferring [20]. GKI could not only promote firms' internal green technology innovation but also help them perceive the market demand for low-carbon economy

and energy conservation. GKI urges firms to cross organizational boundaries to innovate, so firms' external knowledge reconfiguration is inevitable. From the perspective of integration method, firm's green knowledge integration could be divided into socialized green knowledge integration (SOGKI), collaborative green knowledge integration (COGKI), and systematic green knowledge integration (SYGKI). Inside platform firm, SOGKI is embodied by the establishment of shared visions and values to promote knowledge integration. It has characteristics of high integration efficiency, narrow scope, and low flexibility. COGKI is embodied by firms' participation in common business activities to promote knowledge exchange and integration between organizations. It has low integration efficiency, wide scope, and high flexibility. SYGKI is reflected in firm's existing knowledge coding, reorganizing, flowing, and other standardized knowledge processes. It has high integration efficiency, narrow scope, and low flexibility [21]. In platform ecosystem, firm's GKI has many problems (e.g., knowledge vagueness, embeddedness, tacitness, context dependence, specificity, and pricing difficulty, sparse distribution, rapid changing). Some problems lead to the failure of firm's formal governance mechanism. While the low-carbon economy poses high requirements for their green knowledge integration and innovation.

IT not only affects the knowledge network structure of platform ecosystem, but also affects the acquisition, creation, and application of knowledge by influencing information collection, storage, transmission, and processing [14]. Firm's ITC is a complex collection of internal and external IT-related resources, skills, coordination activities, and business practice knowledge of using IT assets to achieve expected goals [22, 23], involving the comprehensive transferring and deploying IT-based and relevant resources [24]. Firm's ITC could significantly promote knowledge sharing and integration with suppliers and customers [25]. Therefore, platform firm could facilitate the sharing and integration of green knowledge by building ITC.

In knowledge activities, firms mainly apply ITC to connect dispersed information carriers, integrate multilevel information, and optimize knowledge networks to enhance their ability to integrate, match, and innovate business processes including knowledge activities [26]. Regarding IT roles in interfirm business, Rai and Tang [27] divided firm's ITC into IT integration capabilities (ITIC) and IT reset capabilities (ITRC) from the perspective of organizational cooperation. ITIC are the abilities to integrate business data, communication technology, and business collaboration systems among firms via IT. They achieve the integration of business processes including knowledge among firms by resolving differences in the information business level (e.g., differences in data structures and business processes) and coordinating differences in software and hardware (e.g., differences in hardware infrastructure and information system compatibility). ITRC are the abilities to expand and reorganize IT resources according to external business needs. They are based on information system modularization, interface standardization, then realizes the support of information technology for adjustment of firm's knowledge activities.

In platform ecosystem, firm's ITC are embedded in the organizational business processes and could promote value chain development via supporting and optimizing business processes: firms utilize ITC to connect knowledge nodes on the platform ecological chain, optimize knowledge network structure and business processes, and improve the efficiency of knowledge activities to support the business ecological chain [28]. During these processes, core firms will actively use IT to establish a knowledge sharing platform to promote business collaboration and knowledge integration. Noncore firms could also use IT to increase their participation in knowledge activities. With the assistance of ITC, platform firms could link external knowledge nodes with external knowledge networks, meanwhile perform explicit coding and rapid transmission of information to achieve rapid aggregation, sharing, and transfer of knowledge. Platform firm's ITC could also realize the intelligent processing, mining, and efficient retrieval of knowledge to facilitate the systematic integration of knowledge [29]. Therefore, ITIC could positively affect knowledge management including GKI. When the demand for energy conservation and emission reduction related to green innovation changes, ITRC could help firms quickly adjust external knowledge networks and coordinate knowledge activities [30], so as to quickly obtain green knowledge needed to support the low-carbon development. Based on the above analysis, this article proposes the following hypotheses:

> Hypothesis 1a (H1a): platform firm's IT capabilities could positively affect the socialized green knowledge integration.

> Hypothesis 1b (H1b): platform firm's IT capabilities could positively affect the collaborative green knowledge integration.

> Hypothesis 1c (H1c): platform firm's IT capabilities could positively affect the systematic green knowledge integration.

2.2. External Informal Knowledge Governance and Green Knowledge Integration

2.2.1. Platform Firm's External Knowledge Governance. The complexity and characteristics (e.g., vagueness, embeddedness, tacitness, and context dependence) of knowledge activities hinder knowledge sharing and transferring. However, in the platform ecosystem, there is a lack of restraints and incentives from contracts, hierarchical organization, culture, economy, etc. Therefore, platform firms need to use relationship and common cognition, trust, agreements, etc. to promote external knowledge transfer [31]. This determines that knowledge organizing and managing need coordination and optimization from governance perspective. Knowledge governance is the process that an organization coordinates knowledge exchanging and sharing between internal and external knowledge nodes to optimize knowledge acquisition, creation, and distribution [32]. Foss and Michailova [33] divide knowledge governance into formal knowledge governance (governance through the

application of formal bureaucratic mechanisms such as power and institutions) and informal knowledge governance (governance through the application of informal mechanisms such as culture and relationship). Firms should choose a more effective combination of governance mechanisms based on specific context to positively affect knowledge sharing and integration.

In platform ecosystem, firms lack formal mechanisms (e.g., relevant rules and regulation, contracts) for external knowledge activities, so their restraint and incentive effects are insufficient. And some problems (e.g., knowledge hiding and pricing difficulty) also hinder the knowledge exchange through market mechanisms. Therefore, informal mechanisms (e.g., relationship governance, network governance) should be applied to influence external knowledge activities [34, 35]. Firm's EIKG is mainly achieved by tapping its social capital (e.g., mutual trust, network relationship, consensus among platform firms) [12, 19, 25]. Firm's social capital is the sum of relationship, cognition, and structure that could affect external information activities and could be used to coordinate knowledge acquisition and sharing among firms [25, 31, 36, 37]. It could be divided into structural capital, cognitive capital, and relational capital [38]. Thus, external informal knowledge governance from social capital perspective for platform firms could be conducted from three dimensions: structure, cognition, and relationship. (1) On the structural dimension, informal governance mainly establishes the niche of the firm through the positioning mechanism on the business ecological chain and affects the platform ecosystem. (2) On the cognitive dimension, informal governance mainly promotes knowledge sharing and open innovation among internal members through the establishment of symbiosis mechanism. (3) On the relational dimension, informal governance mainly relies on trust mechanism establishment among members to maintain and promote the formation and development of the business ecological chain, thereby promoting cooperation between knowledge nodes. Therefore, EIKG of platform firm could be mainly launched from three aspects: positioning mechanism (PM), symbiosis mechanism (SM), and trust mechanism (TM).

2.2.2. External Informal Knowledge Governance and Green Knowledge Integration. As for PM, platform firms mainly have keystone, dominator, and niche positioning [39]. Keystone positioning means platform firm is the initiator and leader of the platform who builds and optimizes the business ecological chain through core technologies and business models, and it creates business niches for other positioning. Dominator positioning firms build key niches in platform ecosystem through business collaboration via key technologies and business links. Niche firms are small ones that are in the gap or on the edge of platform ecosystem who diversifies platform development.

To occupy or re-establish the business niche through technological and business innovation, PM would utilize

internal and external resources, business models, etc., to establish business relationship with other system members [40, 41]. This process is accompanied by the formation, optimization, and reconstruction of firm's external knowledge network. Firm's positioning with greater influence needs more green knowledge, while such positioning could help them consolidate the favorable position in the knowledge network. This positioning would conversely affect their external green knowledge acquisition, absorption, and integration [42].

As for SM, firm's symbiosis is based on labor division and coevolution of the value chain in platform ecosystem [43]. Platform firms establish corresponding symbiotic infrastructure (e.g., industry-university-research platform, supply chain platform). They would collaborate with each other to achieve the low-carbon development of the entire platform. Therefore, they should establish common knowledge activity standards (e.g., knowledge exchanging and sharing process) to facilitate green knowledge sharing and collaboration. In addition, the symbiosis vision could promote platform firms to reach a consensus on cooperation in the organizing, transferring, and sharing of green knowledge. Firm's symbiotic relationship with higher mutual benefit tends to increase green knowledge sharing and open innovation to obtain more green knowledge.

As for TM, trust is the subjective belief that the two parties do not expect opportunistic behaviour from each other, which could prompt firms to advance potential transactions according to expectations without worrying about being misused by other parties [44]. Trust could effectively reduce the risk and uncertainty in green knowledge activities [45]. More trust could also increase the relationship strength between organizations, thereby increasing their green knowledge cooperation, sharing or exchange [46]. Additionally, trust could reduce knowledge transaction costs and increase benefits of knowledge activities [47]. To sum up, EIKG from the perspective of social capital could positively affect green knowledge transfer among platform firms, thus affecting their GKI. Therefore, this article proposes the following hypotheses:

> Hypothesis 2a (H2a): external informal knowledge governance could positively affect socialized green knowledge integration of platform firms.
>
> Hypothesis 2b (H2b): external informal knowledge governance could positively affect collaborative green knowledge integration of platform firm.
>
> Hypothesis 2c (H2c): external informal knowledge governance could positively affect systematic green knowledge integration of platform firms.

2.3. Interactive Effects of IT Capabilities and External Informal Knowledge Governance. The impact of IT capabilities (ITC) on external informal knowledge governance (EIKG). In the

process of applying EIKG, firstly, ITIC could help platform firms establish a knowledge transmission network which could improve the efficiency of green knowledge transfer and reduce costs. Secondly, ITIC could help platform firms systematically integrate data, knowledge in different formats and levels through systematic coding and standardized processing. Furthermore, ITRC could help platform firms adjust their knowledge network to optimize business processes. Therefore, the roles of ITC in the construction of firms' green knowledge network and systematic knowledge processing will directly affect their ecological positioning and knowledge acquisition; the roles of ITC in business collaboration and the establishment of symbiotic relationship could promote the communication in platform ecosystem chain, and strengthen the symbiotic relationship and trust relationship among platform firm. The impact of EIKG on ITC. PM in EIKG would guide platform firm's ITC. The IT strategic thinking under SM could prompt platform firms to use IT in green knowledge transfer and collaboration to attract external firms, thereby expanding green knowledge network in platform ecosystem and green knowledge source. The sustainable development under the SM could guide the construction and application of ITRC (e.g., IT upgrade, business process reengineering). Finally, the application of TM could improve the effects of ITC by reducing the risk of opportunism. Therefore, EIKG could guide and promote the establishment, application, and upgrade of ITC in the process of GKI.

In summary, this article proposes the following hypotheses:

> Hypothesis 3a (H3a): the interactive effect of IT capabilities and external informal knowledge governance has a positive impact on platform firm's socialized green knowledge integration.
>
> Hypothesis 3b (H3b): the interactive effect of IT capabilities and external informal knowledge governance has a positive impact on platform firm's collaborative green knowledge integration.
>
> Hypothesis 3c (H3c): the interactive effect of IT capabilities and external informal knowledge governance has a positive impact on platform firm's systematic green knowledge integration.

Based on the hypotheses above, this paper constructs a conceptual model (Figure 1) about the impacts of platform firm's ITC, EIKG, and their interaction on the sub-dimensions of green knowledge integration.

3. Methodology

To verify the conceptual model and its hypotheses proposed above, empirical research is conducted whose process is shown in Figure 2. In Figure 2, initial scales from literature review are adopted and revised, final scales are formed via preliminary investigation, and sample data are collected via sampling questionnaire survey. These data are subjected to reliability and validity check, then analyzed via multiple
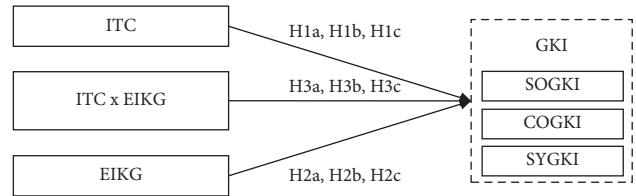

Figure 1: Conceptual model.

linear regression method, and further moderating effects are tested for analyzing the results of hypothesis verification.

3.1. Data Collection. This study uses empirical analysis to verify the proposed conceptual model. Chinese platform ecosystems have developed rapidly in recent years, and they are accelerating their low-carbon transformation, and actively conducting green knowledge integration. Therefore, they provide sufficient samples for this study. The survey subjects are selected from three e-commerce platform ecosystems (Taobao, JD, and Pinduoduo). These three platform ecosystems are relatively mature, and the number of their internal firms is very large. Four types of subjects in these platform ecosystems (core firms, flagship stores, ordinary merchants, and logistics firms) cover the roles of keystone, dominator, and niche firms. There are two ways to issue questionnaires: (1) issuing questionnaires to managers and first-line workers from different departments in core firms of these platforms, and a total of 100 questionnaires are collected; (2) issuing questionnaires to those people from clothing, home appliances, food, book flagship stores, logistics firms via platform instant messenger, and 600 questionnaires are collected. Questionnaire survey was conducted from May to December 2020. Except invalid questionnaires, a total of 372 valid questionnaires are collected.

3.2. Measurement. The questionnaire contains two parts: background information and variable scales. Initial items of variable scales mainly come from existing mature scales, and the indicators use Likert's 7-point scale (1 means "completely disagree/do not conform," 7 means "completely agree/conform"). We firstly used the Delphi method to improve the initial scale by inviting 5 experts to modify the scales for three rounds; then conducted a preliminary investigation on one e-commerce platform (collecting 61 samples of data). Via reliability and validity analysis of the scales, we eliminated two items with underloading factors to get the final scales.

(1) *Green Knowledge Integration (GKI).* The measurement items refer to the research of Long [12], Prieto-Pastor [25], and Mehta [19], including 4 socialized green knowledge integration items (SOGKI1—SOGKI4), 4 collaborative green knowledge integration items (COGKI1—COGKI4), and 4 systematic green knowledge integration items (SYGKI1—SYGKI4).
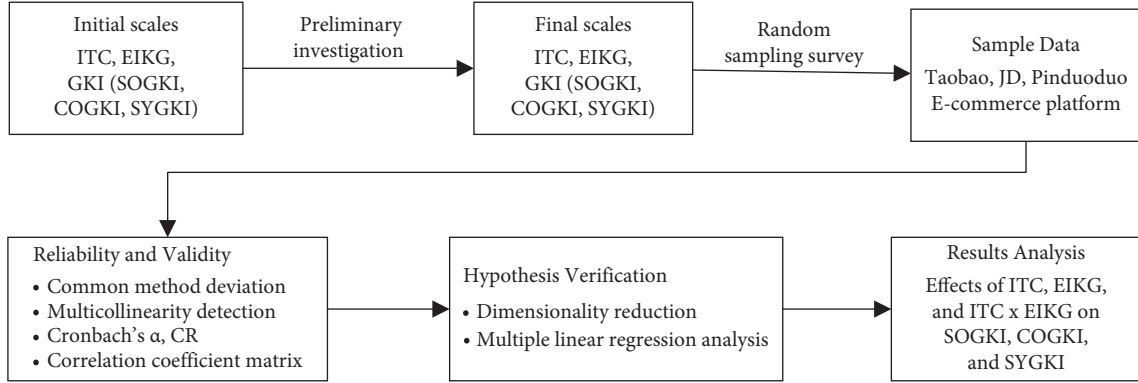
FIGURE 2: Methodology of model verification.

(2) *IT Capabilities (ITC).* The measurement items come from the scale of Rai et al. [27], including IT integration capabilities (ITIC) and IT reset capabilities (ITRC). ITIC includes 3 measurement items (ITIC1-ITIC3). ITRC includes 3 measurement items (ITRC1-ITRC3).

(3) *External Informal Knowledge Governance (EIKG).* The measurement items refer to the research of Iansiti [39], Prieto-Pastor [25], etc., including 3 positioning mechanism items (PM1-PM3), 5 symbiosis mechanism items (SM1-SM5), and 4 trust mechanism items (TM1-TM4).

(4) *Controls.* The age and scale of platform firms are controlled for their possible effects on knowledge integration according to the existing literature [48].

4. Model Test and Analysis

4.1. Validity Test. In multiple linear regression analysis, common method deviation and multicollinearity are two common threats to the validity of research model. And their prevention and check are as follows:

(1) *Common Method Deviation.* After adopting common method deviation prevention technology (e.g., anonymity of questionnaires, terminology annotation, item order changing, 3 reverse questions, and item expression improvement), this study uses Harman's single factor test to check the common method deviation: the KMO value without rotation is 0.917, the chi-square value is 146.172, and the significance level is 0.000. The factor analysis of all items shows that the contribution value of the first principal component factor is 29.743%, so the impact of common method deviation in the study is not significant.

(2) *Multicollinearity Detection.* This study uses variance inflation factor (VIF) as the indicator to check the multicollinearity among variables. The VIFs of ITIC, ITRC, PM, SM, and TM are 4.247, 4.324, 1.751, 2.988, 2.056, respectively. They are all less than 5, so there is no multicollinearity problem among related variables.

4.2. Reliability and Validity Analysis. In this study, exploratory factor analysis and confirmatory factor analysis were applied to check the reliability and validity of the variable scales. The results are shown in Table 1. The Cronbach's α of subdimensions of ITC, EIKG, and GKI in Table 1 are all greater than 0.7, so the scales have good internal consistency. In addition, the minimum CR (construct reliability) of each variable subdimension is 0.806 (greater than 0.7), so the scales have good construction reliability. In summary, the reliability of the scales is acceptable.

In terms of validity, the designing process of the questionnaire ensures the content validity of the scales. In the confirmatory factor analysis, the minimum factor loading of each subdimension is 0.718 (greater than 0.6), the maximum cross-factor loading is 0.336 (less than 0.4), and the minimum value of AVE of all subdimensions in Table 1 is 0.574 (greater than 0.5). In addition, the correlation coefficient values between the variables in Table 2 are all less than 0.7. In summary, the scales have good convergence validity and discriminative validity.

4.3. Hypothesis Verification

(1) *Dimensionality Reduction of Independent Variables.* Since independent variables (ITC, EIKG) are all high-dimensional variables, we firstly use the projection pursuit method [49] to reduce their dimensionality. The projection pursuit method could project non-normal distributed and non-linear high-dimensional data into a one-dimensional space that could reflect their principal information or characteristics and avoid possible mutual influence. Its operation are as follows [50]: (i) Normalize the item data of independent variables with minimum-maximum method: $x^*(i, j) = (x(i, j) - x_{\min}(j))/(x_{\max}(j) - x_{\min}(j))$ ($x(i, j)$ is the value of jth question of sample i, and $x_{\max}(j)$, $x_{\min}(j)$ are the maximum and minimum of the jth question in all samples, respectively). (ii) Construct the projection index function that is the projection direction. (iii) Optimize the projection index function via genetic algorithm. (iv) Calculate the one-dimensional independent variable value

TABLE 1: Reliability and validity analysis of the scales.

Variable	Subdimension	Cronbach's α	CR	AVE
ITC	ITIC	0.789	0.849	0.651
	ITRC	0.747	0.854	0.661
EIKG	PM	0.782	0.806	0.581
	SM	0.791	0.870	0.574
	TM	0.802	0.859	0.605
GKI	SOGKI	0.834	0.877	0.640
	COGKI	0.797	0.895	0.680
	SYGKI	0.827	0.869	0.625

TABLE 2: Correlation coefficient matrix and square root of average variance extraction value ($N = 372$).

Variables	ITIC	ITRC	PM	SM	TM	SOGKI	COGKI	SYGKI
ITIC	**0.807**							
ITRC	0.167*	**0.813**						
PM	0.201	0.213	**0.762**					
SM	0.102*	0.094*	0.431	**0.758**				
TM	0.262	0.309	0.101	0.205*	**0.778**			
SOGKI	0.104	0.239	0.512**	0.357*	0.413**	**0.801**		
COGKI	0.351**	0.287**	0.245	0.401**	0.351**	0.155*	**0.824**	
SYGKI	0.574**	0.197**	0.303	0.198**	0.339	0.203	0.112	**0.791**

Notes: (1) Diagonal elements are the square roots of AVE; (2) $^*p > 0.05$; (3) $^{**}p < 0.05$.

based on the optimal projection direction. Use Python program to calculate the optimal projection directions of ITC and EIKG. They are $a1 = (0.513, 0.401, 0.351, 0.336, 0.412, 0.502)$ and $a2 = (0.310, 0.323, 0.312, 0.216, 0.122, 0.149, 0.287, 0.251, 0.314, 0.402, 0.301, 0.350)$, which are all unit length vectors.

(2) *Multiple Linear Regression Analysis.* To verify the hypotheses proposed above, based on dimensionality reduction of independent variables, this study followed the recommendation of Baron and Kenny [51], step-by-step introduced control variables, independent variables (ITC, EIKG), interactive effect of independent variables, and analyzed the multiple linear regression models with three dependent variables (SOGKI, COGKI, SYGKI). The multiple regression analysis results are shown in Table 3.

As shown in Table 3, the p values corresponding to the F values in all models with independent variables are all less than 0.01, so all models are effective in statistics. After introducing two independent variables and their interactive effects in sequence into the models with three dependent variables, the values of adjusted R^2 are all improved. Therefore, the fit of the model containing interactive effects is better.

In SOGKI submodels, no significant correlation exists between ITC and SOGKI (Model 1), so hypothesis 1a is not supported. While EIKG alone is positively correlated with SOGKI since the coefficient is 0.469 ($p < 0.001$) in Model 2. This supports hypothesis 2a. As for interactive effect of independent variables on EIKG in Model 3, the correlation is highly significant ($p < 0.001$) and positive (the coefficient is 0.191), so hypothesis 3a is supported.

In COGKI submodels, ITC are significantly and positively correlated with COGKI in Model 5 (the coefficient is 0.313, and $p < 0.01$), thus hypothesis 1b is supported. And EIKG has a highly significant positive correlation with COGKI in Model 5 since the coefficient is 0.395, and $p < 0.01$. This provides support for hypothesis 2b. In terms of interactive effect of independent variables in Model 6, the correlation is highly significant ($p < 0.01$) and positive (the coefficient is 0.469), which supports hypothesis 3b.

In SYGKI submodels, ITC and SYGKI are highly significantly positively correlated in Model 8 since the correlation coefficient is 0.465, and $p < 0.001$. Thus, hypothesis 1c is supported. While the correlation between EIKG and SYGKI is not significant, thus hypothesis 2c is not supported. In terms of interactive effect of independent variables in Model 9, the correlation is highly significant ($p < 0.01$) and positive (the coefficient is 0.142). This result yields support for hypothesis 3c.

4.4. Result Analysis

(1) ITC could promote COGKI and SYGKI, but there is no positive correlation of ITC with SOGKI. IT could improve the efficiency of explicit knowledge collection, standardized storage, and transmission. Therefore, the application of ITC could enhance the collaborative and systematic integration of explicit green knowledge among platform firms. The reason for the failure of the relationship between ITC and SOGKI may be that the latter requires the guidance of shared cognition such as symbiotic vision. Therefore, without the aid of EIKG, pure ITC may not be able to promote the SOGKI of platform firms.

TABLE 3: Multiple linear regression analysis.

| | SOGKI | | | COGKI | | | SYGKI | | |
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Controls									
Age	0.175	0.111	0.135	0.113	0.081	0.092	0.074	0.069	0.079
Scale	0.304*	0.227*	0.282*	0.412	0.411	0.405	0.185	0.173*	0.170*
IV									
ITC		0.182	0.177		0.313**	0.308**		0.465***	0.436**
EIKG		0.469***	0.437***		0.395**	0.342**		0.118	0.142
Interactive Effects									
ITC X			0.191**			0.237**			0.305**
EIKG									
R^2	0.054	0.501	0.623	0.035	0.634	0.782	0.022	0.401	0.537
ΔR^2	0.054	0.498	0.620	0.035	0.621	0.763	0.022	0.386	0.528
F	2.103	49.554***	42.968***	2.583	28.526**	25.287**	1.331	35.108***	29.701**

Notes: (1) $^*p < 0.05$; (2) $^{**}p < 0.01$; (3) $^{***}p < 0.001$; (4) Two-tailed test.
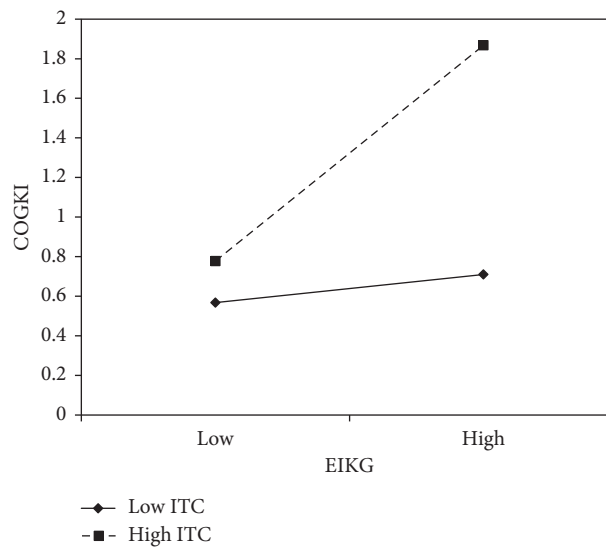

FIGURE 3: Interactive effect of EIKG and ITC on COGKI.

In addition, SOGKI also involves the learning and dissemination of tacit knowledge. These issues may be greatly influenced by factors such as trust, culture, etc., and are not closely related to ITC.

(2) EIKG could promote SOGKI and COGKI, but it has no positive correlation with SYGKI. In platform ecosystem where formal governance mechanism is insufficient, firms could use social capital to influence GKI in terms of ecological positioning, vision, and trust establishment: ecological positioning helps firm occupy the target position of the platform ecosystem (appropriate knowledge network nodes), establish the structural basis for green knowledge integration; the implementation of the symbiosis vision and the establishment of trust will help firm reach a consensus on green knowledge sharing, transaction, etc., reduce uncertainty and opportunistic behavior, thus laying the foundations of cognition and relationship for green knowledge

integration. The construction of these foundations will help platform firms to form a consensus, so as to realize socialized and collaborative green knowledge integration. The reason for the insignificant correlation between EIKG and SYGKI may be that the latter is more dependent on standardized knowledge activity rules. SYGKI may require the guidance of formal governance mechanism such as clear rules and regulations. In addition, large-scale systematic knowledge integration including coding and processing may also require the assistance of information technology such as computer and database.

(3) The interactive effect of ITC and EIKG has a significant positive impact on socialized, collaborative, and systematic GKI. We further analyze these interactive effects. In COGKI submodel (Model 6), the moderating effects of (i) independent variables are mutual, and the interactive effect is shown in

Figure 3. Among them, the correlation coefficients of EIKG and COGKI under high- and low-level ITC are significant. As shown in Figure 3, when ITC are high, EIKG is positively related to COGKI; when ITC are low, this positively significant relationship becomes weaker. The effect of EIKG on COGKI is the same. Hence, COGKI needs not only the guidance of EIKG but also ITC to improve the efficiency of GKI. The former mainly promotes the sharing and exchange of tacit and explicit green knowledge through vision sharing, knowledge network, and trust establishment, thereby reducing the uncertainty and transaction costs in collaborative green knowledge integration; the latter could promote the efficiency and frequency of the COGKI via information system, AI, and other information technology. (ii) In SOGKI submodel (Model 3), interactive effect is only reflected in the moderating role of ITC that positively regulates the relationship between EIKG and SOGKI ($\gamma = 0.191$, $p < 0.01$). This might be because the roles of IT in knowledge activities are mainly reflected in the processing, storage, and transmission of green knowledge. And ITC only have the advantage in knowledge collaboration and exchange. (iii) In SYGKI submodel (Model 9), interactive effect is embodied as the moderating effect of EIKG that positively moderates the relationship between ITC and SYGKI ($\gamma = 0.305$, $p < 0.01$). EIKG could guide the IT integration and reset process from the aspects of external knowledge network construction and the purpose of knowledge systematization, thereby affecting the relationship between ITC and EIKG. To sum up, interactive effect of the two independent variables could be complementary (embodied in a one-way moderating effect) or enhanced (embodied as a two-way moderating effect) in platform firm's green knowledge integration.

5. Conclusion

In the context of the platform ecosystem, from the perspective of firm's social capital, this article explores the impact of platform firm's IT capabilities, external informal knowledge governance and their interaction on green knowledge integration by building a conceptual model about their relationships, and uses 372 sample data to test this model. The final results show that: (i) platform firm's IT capabilities could positively affect the collaborative and systematic green knowledge integration; (ii) platform firm's external informal knowledge governance could positively affect the socialized and collaborative green knowledge integration; (iii) the interactive effect of IT capabilities and external informal knowledge governance has a positive impact on platform firm's socialized, collaborative, and systematic green knowledge integration.

However, there are some possible limitations in the research. Further in-depth study could be conducted from the following aspects:

(1) Distinguish the types of platform firms. Platform firms surveyed in this research are mainly from e-commerce platform ecosystems. Further study could be expanded to those platform firms from other industries.

(2) Conduct in-depth research about the effects of the subdimensions of external informal knowledge governance and ITC on green knowledge integration. Such research could help platform firms build specific capabilities or informal governance to promote the green knowledge integration.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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