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The Effects of External Relations Network on Low-Carbon Technology Innovation: Based on the Study of Knowledge Absorptive Capacity

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Abstract: Low-carbon technology innovations (LTI) have attracted wide attention due to their effects on reducing carbon emissions, and improving LTI behavior is a kind of beneficial measures on carbon emissions control in enterprise. The current research explores the determinants that affect LTI behavioral intention, and an integrative model of external relations network (ERN) on LTI, incorporated with knowledge absorptive capacity (KAC), is used. An effective sample of 380 staffs who worked in industrial enterprise of China was collected, which empirical results reveal the correlation between KAC and LTI, ERN and LTI, and the role of KAC. Hence, this paper discusses the implications for integrative model based on KAC and provides suggestions for improving the ability of LTI, and argues that LTI is not isolated, and it needs to be realized by the combination of ERN and KAC, thus, there should be paying more call for greater attention to ERN and KAC, rather than purely focusing on resource utilization.

Keywords: external relations network; low-carbon technology innovation; technological innovation; knowledge absorptive capacity

1. Introduction

While enjoying the advanced achievements of human's civilization, environmental degradation and energy crisis are increasingly serious to human survival and development due to rapid industrialization, carbon emission and related environmental problems become more and more serious, and all of countries began to explore new methods and technologies to reduce emissions [1,2]. Furthermore, in the backdrop of global emissions, enterprise's environment is more and more complicated, and because of the uncertainty of technology innovation and increasing of integration, the creative ability of individual enterprise is increasingly challenged. The external relations network (ERN) of enterprises plays an important role in supporting and promoting low-carbon technology innovations (LTI) [3], at the same time, knowledge absorptive capacity (KAC) has a causal relationship with LTI [4]. In reality, the LTI not only need good ERN, but also need strong learning ability, such as KAC [5].

Researches on LTI in enterprises have been a hot topic, and many scholars have conducted extensive research about technical aspects, however, as global development trend, LTI is affected by various external factors, such as government policies, environmental pressures, partners, development strategies and so on [4,6]. Among so many influencing factors, enterprises' ERN status play a decisive role in the innovation of low-carbon technology [7], for examples, the government's environmental policy can encourage enterprises to carry out innovation activities [5], market means

motivate enterprises to carry out sustainable LTI, what's more, LTI efficiency is improved by effective cooperation among partners or intermediaries [4]. Besides, innovation is inseparable from the support of knowledge, and there is an intangible knowledge market in the heterogeneous organization formed by enterprises, cooperative organizations, research institutes and intermediaries [6], meanwhile, in the process of LTI, KAC is the prerequisite for effective conversion knowledge and an important determinant for improving the efficiency of low-carbon technology innovation. Recently, a significant amount of literature researches related to LTI, such as driving forces [6], assessment [6], support model [7] and influence factors (Xu et al. 2017) [4], are emerging. However, all of these studies concentrate on the direct impact, and do not involve the impact that different external network characteristics on LTI and KAC play different role in the mechanism of ERN [4]. Now, it is lack of systematic theoretical discussion and empirical research in existing literature, and which is what we urgently need to explore.

Literature review points out that LTI and ERN has received little attention from the academics and practitioners [4,5]. Although a number of factors as predictors of the technology innovation have been studied, the development of theoretical frameworks to interpret research findings has been limited. Therefore, this paper introduced the variable of KAC to explore the role of KAC between ERN and LTI. This study's objective was to understand how ERN affects LTI. The present research also examined the influence of scale, homogeneity, intensity and openness of network on the relationship between ERN and LTI [3]. In essence, this study analyzed the relationship between ERN and LTI, and the role of KAC between ERN and LTI. To achieve the goals, this paper constructs a scale and makes an empirical study to determine the influencing factors and their interaction mechanisms. While developing low-carbon technology, enterprises should pay more attention to ERN and KAC.

The remainder of the paper is organized as follows. The following section describes the ERN, KAC and LTI, then formulates conceptual framework and posit relevant research hypotheses. Section 3 focuses on research methods, and Section 4 focuses on data analysis. In the final section, this paper emphasizes the conclusion of the above results and corresponding suggestions.

2. Literature Review and Hypotheses Development

2.1. Literature Review

2.1.1. External Relations Network

The importance of ERN for enterprise's innovation has been noticed, however, the existing theories cannot explain how ERN affects on LTI [4]. Tenkasi (2003) argued that the implementation and application of strategy were influenced by the intensity of the relationship between the ERN and internal managers of the organization [8]. Agndal (2007) put forwarded that the change of international strategy was directly affected by the established relationship [9]. By the study of Nokia's r&d network, Dittrich (2007) found ERN improved the flexibility, speed and capability of strategic change, and played an important role in the innovation of technology [10]. Peng (2005) suggested that the role of ERN may change with the transition period [11]. Luo (2008) pointed out that technological innovation performance was affected by external environment [12]. Zobel (2017) found that ERN could effectively reduce vicious competition and side-effects of imperfect patent system, and so there is a possibility to build a creative technology environment [13]. Kraatz (1998) argued that strategy changes not only need to analyze internal resource, but also need to analyze the role of networks [14]. Therefore, Kraatz held the view that the external relations network pushed forward an immense influence on enterprise technology innovation. Now, the research on the impact of ERN on technological innovation is still in the initial stage.

In fact, researches on characteristics of ERN are limited, Mitchell (1969) thought ERN characteristics should be divided into network scale, structure and interactivity [15]. After studying ERN, Wu (2006) divided the network characteristics into three dimensions: intensity, scope and openness [16]. Firstly, network scale plays an important role in the business enterprise growth,

especially for new businesses, whose enterprise innovation performance increases with the expanding of network size, and appropriate network scale is an important guarantee for the formation of enterprise innovation ability. Secondly, the higher the network homogeneity, the more competitive the competition among enterprises, will directly or indirectly affect enterprises' cooperative relationship, thus affecting the innovation capability of enterprises. Lastly, there is a significant positive relationship between network strength and resource acquisition ability, and with the enhancement of resource acquisition capability, enterprises' innovation capability is also significantly improved. In the era of knowledge economy, open innovation in highly uncertain environment is one of the sources of enterprise innovation. Comprehensive scholar's points of view, this paper will divide characteristics into four dimensions: scale, homogeneity, intensity and openness.

2.1.2. Knowledge Absorptive Capacity

In the past 20 years, theoretical research on KAC has attracted wide attention from scholars. Especially in the field of strategic management theory, organization theory and innovation theory, a large number of relevant literatures emerged, these literatures focus on the impacts of KAC on organizational learning, knowledge sharing, construction of innovation capability and enterprise performance. Cohen (1990) firstly proposed the concept of KAC, he thought absorptive capacity referred to the ability of companies to search, acquire, digest and ultimately apply to business [17]. According to different impacts of KAC to competitive advantage, Zahra (2002) divided it into potential and actual capacity of absorption [18]. Mowery (1995) put forwarded that KAC was the ability that enterprises acquire tacit knowledge from the outside [19], absorb and transform it into the capabilities of enterprises. Lane (1998) argued that the KAC was the ability of student enterprises to recognize, digest and apply new knowledge [8]. There is no unified conclusion about the component dimension of KAC, some previous researches have concluded that it was the ability to recognize, assimilate and apply external knowledge [17], and some researches divided it into potential capacity and realized absorptive capacity [18], Lane (2006) divided it into exploratory, transformative and exploitative learning [20]. From these viewpoints of scholars, find that KAC is a kind of continuous absorption, digestion and utilization capacity, also an exploratory learning ability to gain knowledge sources from other enterprises and internal and external environment.

2.1.3. Low-Carbon Technology Innovation

There have been many literatures about LTI, but no unified evaluation system. Graeme (2014) argued that LTI was mainly measured by sustainability indicators [21], Lai (2016) thought it largely reflected on breakthrough [13]; Xu (2017) combined the two points of view, and constructed indicators with breakthrough and sustainability [4]. Moreover, Fan (2016) believed that technology innovation must have value, and new low-carbon technologies would be integrated with existing infrastructure [22]. Wakeford (2017) proposed that LTI was an important way for green development, mainly from the continuity and breakthroughs [1]. Comprehensive above scholar's points of view, this paper basically adopts the four indicators: integrated, breakthrough, sustainable and value-added, to measure the innovation of low-carbon technologies.

There are few literatures on studying the impact of LTI to REN, as well as KAC for this development, especially in recent years [4–7]. Many of these studies have analyzed explicit knowledge [4,7] and utilization of knowledge [5–7] as factors to consider in the relationship between LTI and REN. Although research on the REN has become more important, enterprises have not developed mechanisms for it [7]. Well, how external network impact on low-carbon technology innovation? What are the specific forms of expression, and what is the mechanism of knowledge absorbing capability? There is no systematic theoretical analysis and empirical research on the existing literature, and these problems are needed to be further explored. In view of above analysis, this paper puts forward the research topic, the effects of external relations network on low-carbon technology

innovation, introduces the knowledge absorbing ability as intermediate variable, and then puts forward the theoretical model.

2.2. Research Hypothesis

2.2.1. The Research on KAC and LTI

The KAC is of critical importance in the process of technological innovation of enterprises [17], for instance, strong KAC can help enterprise achieve technology innovation and maintain its competitive advantage [18]. If an enterprise is lack of KAC, the knowledge transfer will be hindered, which leading to no knowledge acquire from outside, and innovation ability would be dropped [4,23,24]. Julien (2004) pointed out that KAC played an important role in the process of external relations and technology innovation [25], in other words, enterprises could acquire, integrate and utilize external information and technologies through KAC, finally improve the efficiency of new products development. Zhou (2016) argued that KAC could improve enterprise's technological innovation speed [26], frequency and intensity. Comprehensively, these analyses lead to the first hypothesis:

Hypothesis 1 (H1). *KAC is positively related to LTI.*

2.2.2. The Research on ERN and LTI

According to the existing researches, find that the greater scale of ERN, the more external knowledge opportunity can obtain, and be better to enterprises to grasp market demand and technology innovation [27]. It's homogenization of technology research and development, government policy orientation and culture that support technical innovation in an enterprise's ERN [28]. Furthermore, the stronger ERN, the more opportunities can get to freely communicate with outside world, which faster the response to market information and strong the ability of grasping information [29]. By facilitating the frequent interaction of knowledge, high-intensity ERN could enhance a company's LTI [4], and in the process of technological innovation, only constantly optimize ERN can enterprises acquire related knowledge, and improve characteristics of product to meet market demand [29]. Based on above discussions, the following hypotheses are posited:

Hypothesis 2 (H2). *The ERN is positively related to LTI.*

Hypothesis 2a (H2a). *The size of the external network is positively related to LTI.*

Hypothesis 2c (H2b). *The homogeneity of external network is positively related to LTI.*

Hypothesis 2c (H2c). *The intensity of external network is positively related to LTI.*

Hypothesis 2d (H2d). *The openness of external network is positively related to LTI.*

2.2.3. The Research on ERN and KAC

The KAC is a series of dynamic process, which reflected on the process of acquiring, internalizing, absorbing and utilizing knowledge [18], homogeneous partner and superior external network provide resource for KAC [19]. Yang (2015) believed that companies could hold valuable opportunities of learning in stronger ERN, and acquire advanced knowledge and new skills [29,30]. The formation of KAC is a gradual and persistent process that could promote the integration of knowledge resource, and strengthen the absorption capacity by gathering all kinds of information from outside. Therefore, present the following hypotheses:

Hypothesis 3 (H3). *The ERN and is positively related to KAC.*

Hypothesis 3a (H3a). *The size of ERN is positively related to KAC.*

Hypothesis 3b (H3b). *The homogeneity of ERN is positively related to KAC.*

Hypothesis 3c (H3c). *The intensity of ERN is positively related to KAC.*

Hypothesis 3d (H3d). *The openness of ERN is positively related to KAC.*

2.2.4. The Research on KAC between ERN and LTI

Facing a business environment of knowledge intensive, enterprises have to rely on external sources to promote their technological innovation [31], hence KAC played an intermediary role in the process of ERN and technological innovation [25]. Meanwhile, information and technology could be acquired, integrated and used of via KAC to promote technological innovation, and eventually improve the efficiency of new product development [4,32], so that KAC played an indirect role in the process of technological innovation [27]. Thus, propose the following hypotheses:

Hypothesis 4 (H4). *The KAC positively mediate the relationship between the ERN and the LTI.*

Hypothesis 4a (H4a). *The KAC positively mediate the relationship between the ERN and inclusive innovation.*

Hypothesis 4b (H4b). *The KAC positively mediate the relationship between the ERN and breakthrough innovation.*

Hypothesis 4c (H4c). *The KAC positively mediate the relationship between the ERN and sustainable innovation.*

Hypothesis 4d (H4d). *The KAC positively mediate the relationship between the ERN and Incremental innovation.*

The proposed research model is shown in Figure 1.

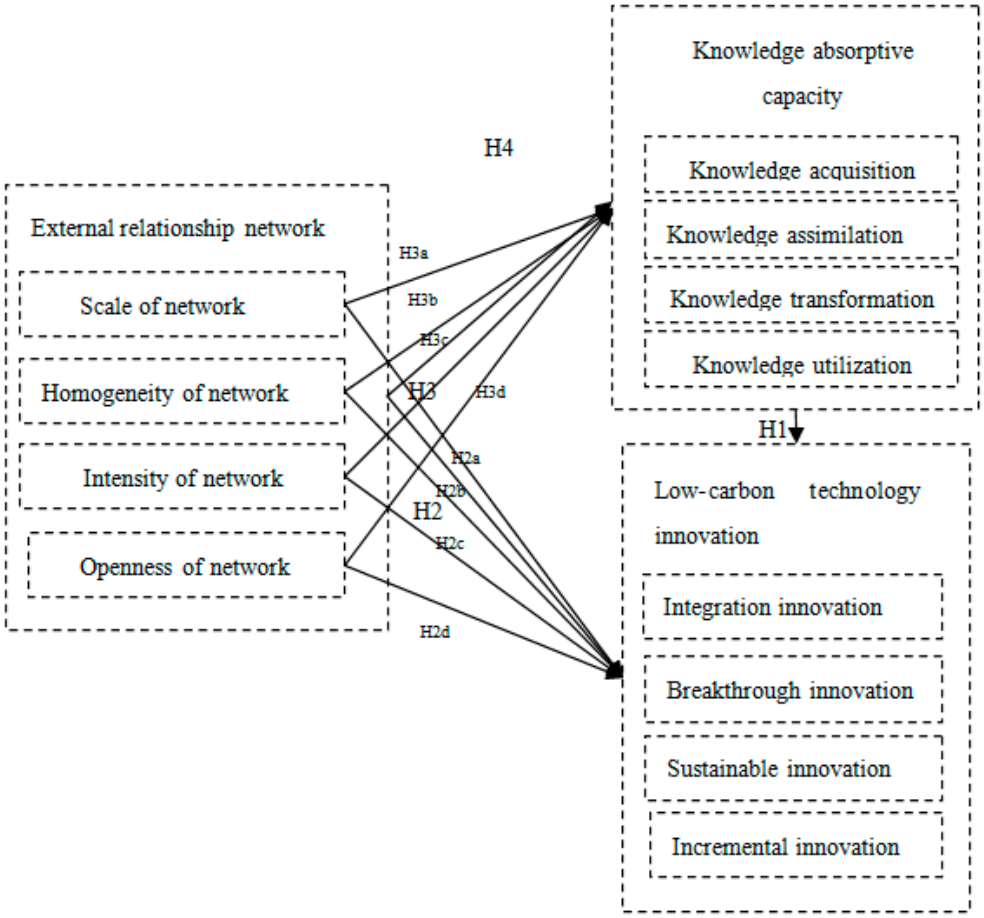

Figure 1. The research model.

3. Empirical Analysis

3.1. Variable Source

This paper selects four dimensions to measure ERN, which are scale, homogeneity, intensity and openness and mainly adopt four variables for KAC, such as acquisition, assimilation, transition, and utilization. Four dimensions of integrated, breakthrough, sustainable and incremental innovation are adopted for LTI. Scale of network is divided into five levels(1 = "≤5", 2 = "5–10", 3 = "11–15", 4 = "16–20", 5 = ">20"), the other dependent and independent variables, a 5-point Likert scale is used to enable respondents could indicate the extent which they agree with these items, where 1 represents strongly disagree and 5 represents strongly agree. The description is shown in Table 1.

Table 1. The research variables.

Variable	Measurement Index	Literature Resources
Scale of network (SN)	The number of enterprises in external relations (NER)	Xie et al., 2013 [27]; Cassiman et al., 2006 [31]; Lechner et al., 2007 [33]
	The number of government agencies in external relations (NGR)	
	The number of research institutions in external relations (NRR)	
	The number of intermediaries in external relations (NIR)	
Homogeneity of network (HN)	Similarities in product (SP) Similarity in technology (ST) Similarity in culture (SC) Market share (MS)	Xie et al., 2013 [27]; Wu et al., 2006 [16]
Intensity of network (IN)	Long-term partnership (LR) Resource sharing frequently (RSF)	Xie et al., 2013 [27]; Wu et al., 2006 [16]
	Information communication frequently (ICF)	
Openness of network (ON)	Links to various social organizations extensively (LVSE)	Xie et al., 2013 [27]; Wu et al., 2006 [16]
	Links to different social organizations extensively (LDOE)	
	Connects with different enterprises extensively (CDEE)	
KAC	Acquisition of knowledge (AK) Assimilation of knowledge (ASK) Transformation of knowledge (TK) Utilization of knowledge (UK)	Cohen et al., 1990 [17]; Zahra et al., 2002 [18]
LTI	Integration innovation (LRI) Breakthrough innovation (LBI) Sustainable innovation (LSI) Incremental innovation (LII)	Xu et al., 2017 [4]; Fan et al., 2016 [22]; Yan et al., 2017 [34]

3.2. Sample and Data Collection

Questionnaires are sent to 52 famous industrial enterprises of 3 provinces in China to collect data. They are Sichuan province, Hubei province and Chongqing municipality, which respectively located in the southwest and middle of China. Because the three provinces and cities are China's low carbon trading pilot areas with a sound system of carbon trading and fine industrial base, industrial enterprises located in these areas have very good representative to validate the assumptions in this paper. The questionnaire survey is carried out by field, interviews and online survey, and project team selected 8 undergraduates, respectively to different target enterprises interview with relevant personnel, audit and review of the questionnaire to ensure that the survey data from real, objective and complete. 1500 questionnaires are sent out, and 489 responses are received, including 380 valid and the rate of effective recovery is 25.3%, the sample description is shown in Table 2. The dominant age group

is aged between 28 and 50 (88.2%); managers accounted for 70.4%, 73% of respondent shave more than three years of working age, and education degree above bachelor degree is 82.4%, 79.4% of enterprises had been established more 5 years, and enterprises scale with more than 300 people account for 70.4%. Then, with the help of SPSS 21.0 (IBM, Armonk, NY, USA), this paper analyzed the collected survey data and examined the research hypotheses.

Table 2. Sample demographics.

Method of Investigation	Quantity of Questionnaire	Recycling Quantity	Effective Questionnaire Quantity	Effective Ratio of Recovery
Email	600	123	108	18%
Field research	400	189	124	31%
Interview survey	500	177	148	29.6%
Total	1500	489	380	25.3%

3.3. Reliability and Validity

Before testing the hypotheses, it is necessary to test the reliability and validity, and the results are shown in Table 3. As shown in Table 3, the lowest value of Cronbach's alpha is 0.701, and the composite reliability is 0.783, which all exceed 0.7, thus confirming their reliability. The three hidden variables and the Cronbach's alpha coefficients of their dimensions reach a higher level, which indicates the scale has a good reliability. Also, Table 3 shows that Kaiser-Meyer-Olkin is above 0.7, and most cumulative factor explanations are more than 0.70, which shows that the table has good construction validity. Therefore, concluded that the measurement model with adequate reliability and validity.

3.4. Exploratory Factor Analysis

Table 3 shows that the P value of Bartlett sphere inspection is less than 0.001, which indicates the data is suitable for further factors analysis. By taking exploratory factor analysis of KAC and LTI (Table 4), find that the common degree of each variable is more than 0.6. Therefore, the factor analysis is better.

Table 3. Reliability and validity.

Variable	Dimensionality	Cronbach's Alpha		KMO		Factor Interpretation Quantity (%)
ERN	SN	0.721	0.845	0.764	0.842	65.74
	HN	0.832		0.784		74.82
	IN	0.748		0.764		72.76
	ON	0.768		0.690		72.69
KAC	AK	0.746	0.857	0.756	0.863	73.48
	ASK	0.782		0.774		68.52
	TK	0.824		0.802		78.65
	UK	0.759		0.702		64.72
LTI	LRI	0.701	0.783	0.782	0.853	69.82
	LBI	0.784		0.824		72.43
	LSI	0.837		0.749		74.58
	LII	0.786		0.752		75.42

Table 4. The exploratory factor analysis of KAC and LTI.

Variable	KAC	LTI	Common Degrees
AK	0.854	NA	0.745
ASK	0.874	NA	0.768
TK	0.789	NA	0.648
UK	0.826	NA	0.675
KMO = 0.821; Bartlett's test of sphericity X^2 = 706.307; df = 6; sig. = 0.000			
LRI	**NA**	0.754	0.582
LBI	**NA**	0.785	0.635
LSI	**NA**	0.809	0.665
LII	**NA**	0.816	0.674
KMO = 0.803; Bartlett's test of sphericity X^2 = 470.417; df = 6; sig. = 0.000			

4. Results and Discussion

4.1. Correlation Analysis

This paper did a Pearson analysis of the related variables and the results are shown in Table 5. The results show that there is a significant correlation among KAC, ERN and the four dimensions of LTI. However, the correlation coefficient between openness of network and LTI is 1. In order not to affect the regression effect, need to remove the variable (ON) from the regression model.

4.2. Multiple Regression Analysis of the Mediation Effect

The return of mediation effect could be divided into three steps: (1) firstly, measure the relationship between ERN and LTI; (2) secondly, measure the relationship between ERN and KAC; (3) lastly, bring ERN and KAC into regression equation, to measure the relationship between the two (ERN and KAC) and LTI. At this point, the value of the independent and dependent variable is smaller than the value of the first step and it's not significant, which means that the assumption is completely true, and the significant is partly true, the relationship between the mediator and the dependent variable should remain significant.

Table 5. Means, standard deviations, and correlations (N = 380).

Variable	Means	SD	1	2	3	4	5
SN	2.3758	1.01327	1	NA	NA	NA	NA
HN	3.6648	0.67689	0.132 *	1	NA	NA	NA
IN	3.9207	0.60057	0.125 *	0.473 **	1	NA	NA
ON	3.5648	0.71048	0.231 **	0.462 **	0.468 **	1	NA
KAC	3.8205	0.49578	0.139 **	0.534 **	0.653 **	0.554 **	1
LTI	3.5607	0.71076	0.238 **	0.425 **	0.458 **	1.000 **	0.552 **

Means are measured based on average factor scores; SD means standard deviation; ** shows significance at the level of 0.01; * shows significance at the level of 0.10.

(1) The impact of KAC and ERN on LTI

By using KAC as independent variable and LTI as standard variable to make regression analysis, the results are shown in Table 6. F value is 156.308 in the regression equation, and $p < 0.001$. The regression equation is significant, especially the effect of KAC is significant, $\beta = 0.532$ besides $p < 0.001$. It is evident that KAC has a significantly positive effect on LTI, thus the H1 is verified. Similarly, use three dimensions of ERN as independent variables and LTI as standard variable to do multiple regression analysis. The F value is 52.521 ***, and $p < 0.001$, the regression equation is significant, especially the effect of KAC is significant, $\beta = 0.532$ besides $p < 0.001$, so the equation is significant. Meanwhile, the β value of the three variables (SN, HN and IN) respectively are

0.156, 0.231 and 0.354. The three dimensions on the confidence level of 0.000 have remarkable positive influence on the enterprise of LTI. Thus, H2a, H2b and H2c are verified.

Therefore, enterprises can achieve LTI by expanding the scale of the network, strengthening the homogeneity of the network and improving the network strength. The government should develop a series of policies to improve the functions and service quality of intermediaries, encourage technological collaboration between enterprises and research institutions, and constantly improve the performance of research institutions and intermediaries.

Table 6. The multiple regression analysis of KAC and ERN to LTI.

Independent Variable	LTI		Independent Variable	Innovation Performance	
	β	*t*		*β*	*t*
KAC	0.532	12.507 ***	SN	0.156	3.528 ***
			HN	0.231	4.646 ***
			IN	0.354	6.976 ***
F	156.308 ***		F	52.521 ***	
R^2	0.286		R^2	0.294	
ΔR^2	0.289		ΔR^2	0.289	

*** shows significance at the level of 0.001.

(2) The impact of ERN on KAC

This paper used the three dimensions of ERN as independent variable, KAC as standard variable to do multiple regression analysis, and results are shown in Table 7. The F value is 116.273 and $p < 0.001$, so the regression equation is significant. But the impact of SN on the three dimensions is not significant, the β values of the three variables (SN, HN and IN) are 0.041, 0.282 ($p < 0.001$), and 0.512 ($p < 0.001$) respectively, which indicates that ERN characteristics can enhance the ability of knowledge absorbing, so H3b and H3c are validated.

Therefore, enterprises can strengthen and improve intensity and homogeneity of network through technological cooperation and information communication in ERN, so as to acquire more external knowledge and fully explore the value of external knowledge. Finally, enterprises improve their knowledge absorption capacity.

(3) The intermediate effect of KAC

By taking independent variables and mediation variables into the regression equation, the results are shown in Table 8. The F value is 51.435 and $p < 0.001$, so the equation is significant. The β value of the three variables (SN, HN and IN) are 0.153, 0.142, 0.168, and the three variables are significant (at significance level of 1%).Due to the fact that regression coefficient of independent variables fall than before (3.528 > 3.362, 4.646 > 2.728, 6.976 > 3.153), but still be significant, furthermore the regression coefficients of intermediary variable (KAC) is significant on the confidence level of 0.001. Thus, the three variables of ERN exist partial mediation effect H4a, H4b, H4c are verified.

The results show that the expansion of the network, improving network strength, strengthening the ability of the network homogeneity can enhance the ability to obtain operational resources, and operational resources can be transformed into LTI through absorption, integration, utilization and innovation. Therefore, in order to promote the innovation activities, enterprises should enhance their ability to transfer and apply skills and knowledge in ERN.

Table 7. Multivariate regression analysis of KAC to ERN.

Independent Variable	KAC	
	β	t
SN	0.041	1.053
HN	0.282	6.525 ***
IN	0.512	11.889 ***
F	116.273 ***	
R^2	0.478	
ΔR^2	0.482	

*** shows significance at the level of 0.001.

Table 8. Mediating effect of KAC.

Independent Variable	LTI	
	β	t
SN	0.153	3.362 **
HN	0.142	2.728 **
IN	0.168	3.153 **
Mediating variable		
KAC	0.342	5.795 ***
F	51.435 ***	
R^2	0.346	
ΔR^2	0.412	

*** shows significance at the level of 0.001; ** shows significance at the level of 0.01.

5. Conclusions and Suggestions

This paper introduces KAC and explores how ERN effect on LTI. There are some conclusions and suggestions as followed.

5.1. Conclusions

Based on the empirical results, this paper draws the following two conclusions.

(1) The ERN and LTI are positively correlated. Excellent quality of ERN shows that the external relations are durable and stable. It is benefit to carry out LTI by achieving information communication and technology innovation cooperation smoothly.

(2) The KAC plays an intermediary and positive role in ERN and LTI. After introducing KAC, the indirect effect is more significant, it shows that KAC plays a mediating role in between ERN and LTI.

5.2. Suggestions

In this paper, the research results show the three dimensions of ERN as well as KAC and LTI are significantly positive correlation, and KAC has an intermediary effect on ERN and LTI. Based on above findings, put forward the following suggestions.

(1) The ERN of enterprises is positively affecting LTI.

The superior ERN helps companies form a sustainable and stable innovation alliance, realize mutual information communication and technical innovation cooperation, ultimately benefit the implementation of LTI. In the era of open innovation, if an enterprise wants to achieve sustainable development, they need to build a long-term and stable cooperative relationship with different innovative partners in terms of resources, technical cooperation, and information etc.

The impact of corporate ERN on LTI is a gradual process, besides good internal and external resources, enterprises also need to continuously obtain external innovation resource to form their own core competitiveness.

(2) Knowledge management is a core tool to enhance innovation ability and performance.

There is a need to establish and improve various systems of knowledge management, and gain innovative knowledge via ERN. In the process of operation, companies need to continuously enhance their KAC to obtain innovation output and new technology. At the same time, companies also need to strengthen the bond of research institutions, universities, intermediary institutions, government etc., and build a good ERN. In addition, enterprises also need to improve their sensitivity and perception of external knowledge, get kinds of new knowledge and technology from the external resources.

There are some drawbacks in the study. (1) The sample largely select part of industrial enterprises in Sichuan province, Hubei province, Chongqing municipality, and based on the limitations of industrial enterprises, the adaptability of the conclusion had yet to be further verified and discussed; (2) This paper discussed the intermediary effect of KAC in ERN and LTI, and do not consider whether there would be a regulatory effect, and no in-depth discussion.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Major Questionnaire Items

The questionnaire is designed around the theme of this paper, which is to verify the effects of external relations network on low-carbon technology innovation: based on the study of knowledge absorptive capacity, and introduce the variable of knowledge absorbing ability. In the process of questionnaire design, we obey the rule of rationality, clarity, non inducibility and easy to arrange analysis, bedsides reference to the mature scale, finally set the questions according to main variables ERN, KAC, LTI and related measurements. Following is a questionnaire designed for this objective.

Section A: Basic profile

1. What your gender? 0. Female 1. Male
2. Your position? 1. Technical workers 2. General manager 3. Senior manager 4. Others
3. What is your highest level of education? 1. Junior middle school or below 2. Senior high school 3. Junior college or bachelor's degree 4. Master degree or PhD
4. How long have you been working in this enterprise? 1. Less than 5 years 2. 5–10 years 3. 10–20 years 4. More than 20 years
5. How long has your company been established? 1. Less than 5 years 2. 5–10 years 3. 10–20 years 4. More than 20 years
6. The size of your company? 1. Less than 100 people 2. 100–300 people 3. 300–1000 people 4. More than 1000 people

Section B: Measurement items of the constructs

Components of ERN variables (adapted from Xie et al. 2013; Cassiman et al. 2006; Lechner et al. 2007)

Scale of network (SN)

SN1. How many enterprises does your company work with among external relations?

SN2. How many governments' agencies does your company work with among external relations?

SN3. How many research institutions does your company work with among external relations?

SN4. How many intermediaries does your company work with among external relations?

Homogeneity of network (HN)

HN1. The similarity of products produced by your company.

HN2. The similarity of technology in your company.

HN3. The similarity of culture in your company.

HN4. The status of market share in your company.

Intensity of network (IN)

IN1. Your company has a long-term cooperation with other enterprises.

IN2. Your company frequently shared resources with other enterprises.

IN3. Your company frequently exchanged information with other enterprises.

Openness of network (ON)

ON1. Your company is widely connected to social organizations with different scales.

ON2. Your company is widely connected to social organizations with different regions.

ON3. Your company is widely connected to different enterprises.

KAC (adapted from Cohen et al., 1990; Zahra et al., 2002; Xie et al., 2013)

Acquisition of knowledge (AK)

AK1. The company can master the service demand well.

AK2. The company is aware of service technologies or products well.

AK3. The company has an efficient cooperation with research institutions.

AK4. The company can effectively carry out the training of talent.

Assimilation of knowledge (ASK)

ASK1. Employees can master technical knowledge and information well.

ASK2. Employees have higher education level and professional skill level.

Transformation of knowledge (TK)

TK1. Employees' degree of knowledge structure complementation is good.

TK2. Employees can share information and experience.

TK3. Employee compensation has a strong correlation with its innovative contribution rate.

Utilization of knowledge (UK)

UK1. The company has a strong ability to develop new services and markets.

DN2. The company has a greater success rate in the development of new service projects.

DN3. The company' physical change level of new knowledge is good.

LTI (adapted from Xu et al., 2017; Xie et al., 2013; Fan et al., 2016)

Integration innovation (LRI)

LRI1.What do you think of the fusion innovation of corporate replication?

LRI2. What do you think of the fusion innovation of enterprise reform?

LRI3. What do you think of the fusion innovation of corporate grafting?

Breakthrough innovation (LBI)

LBI1. The company' low-carbon technology level among the industry.

LBI2. The market occupation rate of new low-carbon products.

LBI3. The R & D investment of low-carbon technology.

Sustainable innovation (LSI)

LSI1. The company' innovation cycle of low-carbon technology.

LSI2. The trend of low-carbon technology innovation in Enterprises.

LSI3. The company' predictability of low-carbon technology innovation.

Incremental innovation (LII)

LII1. Low-carbon technology innovation makes profits.

LII2. Low-carbon technology innovation lowers the cost.

LII3. Low-carbon technology innovation adds additional products.

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