



Relationship Between External Search Breadth and Process Innovation Performance Under the Background of Big Data

Yanxia Ni¹(✉) and Jiangman Yu²

¹ Jiangnan University Business School, Wuhan 430056, China

² Hubei University of Technology, Wuhan 432200, China

Abstract. With the advent of the era of big data, this article selects the 2014 World Bank survey data on Indian private companies from the perspective of knowledge search channels, and analyzes the relationship between external search breadth and enterprise process innovation performance from the perspective of organizational learning theory, and it also explores the moderate effect of the attention allocation process, namely, senior management's tenure and financing constraint. The research finds that: External search breadth and enterprise process innovation performance have an inverted U-shaped relationship. Senior management's tenure plays a positive moderate role. In addition, in order to ensure the correctness and reliability of the selected model, the paper tests the applicability and endogenous problems of the inverted U-shaped model of the sample. The research conclusions provide a theoretical reference for companies to effectively allocate attention and improve their ability to benefit from external search.

Keywords: Big data · External search breadth · Process innovation · Attention-based view · Organizational learning theory

1 Introduction

In the current era of increasing data resources, competition among enterprises increasingly depends on whether enterprises can create knowledge and commercialized innovation achievements in a fast and effective way. However, under the impact of big data, how to accurately, efficiently and conveniently analyze the impact of external knowledge on innovation results has become a realistic problem facing organizations. So more and more companies are implementing external search strategies to actively identify and integrate external knowledge from sources such as partners, competitors, consultants, business laboratories, education institutions and industry associations [1]. Despite the widespread recognition of the importance of external search, extensive knowledge searches often fail to achieve the desired results. Predecessors' research is also full of contradictions about how external search breadth affects corporate innovation performance [2]. This raises a very important theoretical question for us: When can companies realize the benefits

of innovation from external search strategies? Why can some companies benefit more from external search strategies, while others cannot?

The external search strategy is an activity way for organizations to solve problems, involving the creation and restructuring of technological ideas. External search strategy can be characterized by the breadth and depth of knowledge search [3]. The external search breadth represents the number of different organizational sources from which the enterprise seeks knowledge, while the external search depth is the extent to which the enterprise searches knowledge from each external topic. Because of costs and risks, it is a difficult task for companies to obtain the desired innovations from a wide range of knowledge searches. Noting these issues, more and more research in recent years has begun to focus on when companies can overcome these obstacles and improve the efficiency of external search strategies. Although attention resource limitation is widely regarded as a key factor that hinders enterprises from effectively acquiring, absorbing and integrating external knowledge, how to weaken the negative influence of attention resource on external search strategy is rarely discussed. In addition, most of the existing research on the relationship between external search and innovation focuses on product innovation. But research on external search and process innovation is limited with customer-oriented product innovation process innovation can reconfigure the value chain, thus reducing production costs, improving product quality and manufacturing flexibility. Therefore, process innovation involves more tacit knowledge, is not easy to be transferred to imitation, and is more likely to bring competitive advantage to the organization. Therefore, it is particularly important to study the relationship between external search and process innovation.

Therefore, this paper analyzes the relationship between external search breadth and process innovation from the perspective of organizational learning theory and attention-based view, thus expanding our understanding of relationship between external search, attention distribution and enterprise process innovation performance. First, this paper analyzes the relationship between external search breadth and enterprise process innovation performance. Second, this paper examines the moderating effect of factors affecting attention distribution. Finally, to ensure the robustness of empirical results, this paper uses both the ordered counting model and the Poisson distribution model, and examines the endogeneity of the sample.

2 Literature Review and Research Hypothesis

The Organization for Economic Co-operation and Development (OECD) defines process innovation as “a new or significantly improved way of producing or delivering, including major changes in technology, equipment or software” [4]. In most cases, the main purpose of product innovation is to develop new products to meet the needs of customers. The main purpose of process innovation is to shorten lead times, reduce operating costs, and increase operational flexibility. Compared with product innovation, process innovation is more complex. And it consists of tacit knowledge related to organizational system knowledge. The development of process innovation is also slower, requiring more trial and error and experience learning to achieve its hidden value.

2.1 External Search and Process Innovation

Although the advantages brought by the breadth of knowledge search are obvious, there is no agreement on how the external search breadth affects the process innovation performance. First, due to the limited ability of enterprises to absorb knowledge, the effective understanding and rational integration and application of diverse external knowledge may make external search negatively affect the process innovation performance of enterprises. Second, with the increase of the external search breadth of enterprises, the difference of knowledge is gradually increasing, which increases the difficulty of knowledge exchange and combination among enterprises. The cost of identifying, absorbing and integrating external knowledge increases, which weakens the positive effect. Third, because the manager's attention resources are limited, the manager can only allocate limited attention resources, and it is impossible to make full use of all external knowledge. Finally, tacit knowledge, as an important strategic resource owned by the organization, is difficult to transfer or replicate. Therefore, the tacit knowledge obtained in the external search must be accompanied by the loss of substantive knowledge, making the cost of external search exceed the benefits it brings.

Based on this, this paper proposes the following hypothesis:

H1: The relationship between external search breadth and process innovation performance is inverted U-shaped.

2.2 The Moderating Effect of Attention

From the previous analysis, it is known that the limited attention of managers is one of the key antecedents that lead to the negative effect of external search breadth. Participants and organizational resources are important factors influencing the organization's attention distribution, and also constitute an important part of the attentional structure distribution [5]. This paper selects the executive tenure and financing constraints as the proxy variables of the participants and organizational resources.

Participants: The Moderating Effect of Executive Tenure

The executive tenure is one of the important factors affecting the decision-making behavior of managers, which may affect the acquisition and absorption of external knowledge.

First, managers with different tenures have different reserves of knowledge about enterprises and external environment, which affects the selection and elimination of information required by managers in enterprise process innovation. Long-term managers have a deeper understanding of corporate culture and internal resources, and have a deeper understanding of the types of external knowledge required by enterprises. Therefore, they can identify the most valuable resources for enterprises and get them more quickly and effectively. Managers with short term tenure are likely to receive a wide range of external knowledge, make unfavorable decisions for the company, cause waste of enterprise resources, and delay the best time for process innovation.

Secondly, managers with different tenures have different concerns. Managers with long term tenure pay more attention to the development of long-term goals of the company due to the stability of positions and salary, so they will pay more attention to the

use of knowledge that is conducive to enterprise innovation. The short-term manager's concerns are mostly in the management of labor relations and external relations, and the supervision and assessment of managers with short term tenure are more strictly, and the threat of positions is even more serious. They will focus more on improving the short-term performance of the company and ignoring the long-term value of the company.

Based on this, this paper proposes the following hypothesis:

H2: Executive tenure positively moderates the relationship between external search breadth and process innovation performance.

Organizational Resources: The Moderating Effect of Financing Constraints

We believe that the interaction between financing constraints and external search breadth will have an impact on enterprise processes innovation performance. The increase of financing constraints makes the financial capital of enterprises limited, which encourages enterprises to pay more attention to the use of internal knowledge, reduce the participation of enterprises in other cognitive activities, and reduce the efficiency of enterprises in identifying, absorbing, integrating and using external knowledge. Compared with internal knowledge, the search and application of external knowledge is more risky, more uncertain, and more costly due to the existence of opportunism and speculation in the transaction, unpredictable factors in the environment, and so on. In financial markets with high financing constraints, due to the restriction of funds, enterprises will pay more attention to the use of existing resources and knowledge within the enterprise.

Based on the above analysis, this paper proposes the following assumptions:

H3: Financing constraints negatively moderate the relationship between the external search breadth of firms and process innovation performance.

3 Research Design

3.1 Research Sample

The data is taken from the World Bank's 2014 survey data on private enterprises in India. The purpose of the survey is to understand the business environment, the impact or restrictions of the business environment on private enterprises, and the innovation of private enterprises. The survey data consists of two parts. The first part mainly investigates the investment environment and financial data of the company. The second part is the innovation follow-up survey data. In order to ensure the validity and robustness of the empirical results, this paper deletes the sample of the service industry after matching the two parts of the data according to the enterprise code, only retains the sample of the manufacturing industry, and deletes the missing value of the corresponding variable, and finally The sample have 395 companies in 19 sub-sectors.

3.2 Indicator Selection and Variable Definition

Independent Variable. External Search Breadth (Procb) is the cumulative type of organization that has a relationship with the company in process innovation [6, 7].

Dependent Variable. A large number of scholars have divided innovation into two categories: new to the market and new to the world [8]. The proxy variable of the process innovation performance (Procin) is the main process innovation level in the enterprise. The question in the second part of the questionnaire is “whether the main process innovation of the enterprise (1) is new to the local market; (2) The domestic market is new; (3) it is new to the international market.”

Control Variable. The control variables selected in this paper include company size (Size), firm age (Age), human capital (Human), R&D (Research and Development), whether the company is located in the main trading city (City), and government control (Gover).

3.3 Model Estimation

Since the variable process innovation (Procin) is an ordered discrete non-negative integer, this paper uses the ordered counting model (Oprobit) for the estimation. In addition, in order to ensure the robustness of the estimation results, we also examine the endogeneity of the sample and use the basic model Poisson as the robustness test of the sample. Since the main effect assumed in this paper is an inverted U-shaped relationship, and the hypothesis of regulating the relationship of this curve is proposed, this paper adopts the three-step method of confirming the U-type relationship proposed by Haans et al. [9]. First of all, as shown in Eq. (1), β_2 must be significantly negative. Second, the slope of the two extremes of the range of independent variables must be sufficiently steep. If X_l is used to represent the low end portion of the X value and X_h is the high end portion, then the second condition should be guaranteed: $\beta_1 + 2\beta_2X_h$ is significantly negative, and $\beta_1 + 2\beta_2X_l$ is significantly positive. Third, the turning point of the U-shaped curve must be within the variation range of the sample data of X. In the calculation of the confidence interval of the independent variables, this paper uses the Fieller algorithm to calculate the confidence interval of 90% of the independent variables. In addition, in order to avoid the model being S-type, it is also necessary to guarantee the cubic coefficient γ_3 of the independent variable in Eq. (2) non-significant. Therefore, the final model of this paper is shown in (3) and (4)

$$Y = \beta_0 + \beta_1X + \beta_2X^2 \tag{1}$$

$$Y = \gamma_0 + \gamma_1X + \gamma_2X^2 + \gamma_3X^3 \tag{2}$$

$$\text{Pr } ocin_i = a_i + b_i \times \text{Pr } ocb_i + c_i \times \text{Pr } ocb_i^2 + d_i \times CV + \varepsilon_i \tag{3}$$

$$\begin{aligned} \text{Pr } ocin_i = & a_i + b_i \times \text{Pr } ocb_i + c_i \times \text{Pr } ocb_i^2 + d_i \times MV \times \text{Pr } ocb_i \\ & + e_i \times MV \times \text{Pr } ocb_i^2 + f_i \times MV + \varepsilon_i \end{aligned} \tag{4}$$

Among them, the dependent variable $\text{Pr } ocin_i$ is the process innovation performance of the enterprise. The independent variable $\text{Pr } ocb_i$ is the external search breadth. CV is the control variable. MV is the adjustment variable. ε_i is the error term.

In addition, there may be endogenous problems in this paper. In order to solve this problem, this paper uses the Conditional Mixed Process proposed by Roodman [10] to test and deal with the endogeneity in the ordered counting mode. The choice of instrumental variables must be an exogenous variable that has no direct connection to the innovation performance of the enterprise process, but can strongly influence the breadth of the external search. Therefore, the “degree of resistance to input and supply” directly affects the external search breadth of the enterprise, but it does not affect the process innovation performance of the enterprise. Therefore, this paper takes “the degree of obstruction of input and supply” as a tool variable for the external search breadth.

4 Empirical Results and Analysis

4.1 Descriptive Statistics

Table 1 reports the descriptive statistics of each variable and the Pearson correlation coefficient matrix. It can be seen that the external search breadth and process innovation performance are not significantly positively correlated, and further tests are needed [11]. In addition, the results of multicollinearity analysis showed that the variance expansion factor (VIF) did not exceed 2, indicating that there is basically no multicollinearity problem between variables.

Table 1. Descriptive statistics of variables and Pearson correlation coefficient matrix

Variable	Procin	Procb	R&D	Age	Human	City	Gover	Tenure	Finance
Procin	1								
Procb	0.01	1							
R&D	0.16 ^{***}	-0.02	1						
Age	0.11 ^{**}	0.08	0.14 ^{***}	1					
Size	0.16 ^{***}	-0.04	0.19 ^{***}	0.18 ^{***}					
Human	0.09 [*]	-0.20 ^{***}	0.05	-0.02	1				
City	-0.02	-0.01	0	-0.05	0.18 ^{***}	1			
Gover	-0.02	0.06	0.01	0.01	0.05	0.06	1		
Tenure	0.02	0.01	0.09 [*]	0.38 ^{***}	0.06	-0.01	0.11 ^{**}	1	
Finance	0.06	0.06	-0.07	-0.04	0.09 [*]	0.15 ^{***}	-0.01	-0.10 ^{**}	1
Mean	0.53	0.1	124.99	22.09	0.67	0.84	4.1	15.69	0.98
St.d	0.76	0.39	798.33	14.01	0.25	0.37	14.22	10.26	1.07
VIF	—	1.06	1.06	1.23	1.1	1.06	1.02	1.2	1.07

Note: The observed value is n = 395; The superscripts ^{***}, ^{**}, and ^{*} represent statistical significance of 1%, 5%, and 10% respectively.

4.2 Preliminary Regression Results and Endogenous Analysis

Table 2 reports the preliminary regression results using the ordered counting model.

Table 2. Preliminary regression results

Variable	1	2	3	4	5
Procb	0.640**	0.720**	0.596	0.250	-2.872***
	(1.99)	(2.41)	(1.58)	(0.36)	(-10.39)
Procb ²	-0.265*	-0.412***	-0.232	0.237	-0.023
	(-1.89)	(-2.64)	(-1.28)	(0.37)	(-0.27)
Procb ³				-0.142	
				(-1.19)	
R&D	+ 0.000***	+ 0.000***	+ 0.000***	+ 0.000***	-0.000
	(3.18)	(3.09)	(3.15)	(3.18)	(-1.17)
Firmage	0.010**	0.011**	0.010**	0.010**	0.002
	(2.11)	(2.13)	(2.04)	(2.09)	(0.38)
Size	0.035	0.034	0.036	0.035	-0.024
	(0.57)	(0.55)	(0.57)	(0.56)	(-0.50)
Human	0.519*	0.538*	0.507	0.515*	-0.708**
	(1.66)	(1.69)	(1.58)	(1.65)	(-2.35)
City	0.068	0.096	0.073	0.066	0.119
	(0.33)	(0.47)	(0.35)	(0.32)	(0.64)
Gover	-0.006	-0.008*	-0.006	-0.006	0.003
	(-1.41)	(-1.90)	(-1.48)	(-1.40)	(0.79)
Procb*Tenure		0.117**			
		(2.53)			
Procb ² *Tenure		-0.066**			
		(-2.37)			
Tenure		-0.005			
		(-0.71)			
Procb*Finance			-0.120		
			(-0.33)		
Procb ² *Finance			0.035		
			(0.21)		
Finance			-0.002		
			(-0.03)		

(continued)

Table 2. (continued)

Variable	1	2	3	4	5
atanhrho_12					3.263
_cons					(0.91)
Wald chi2	826.32***	854.27***	831.87***	1285.29***	14135.03***
Pseudo R ²	0.117	0.122	0.117	0.117	
N	395	395	395	395	395

Note: ***, **, and * represent statistical significance of 1%, 5%, and 10%. The regression coefficients in parentheses () are z values. The regression coefficients in parentheses [] are p value.

Model 1 Table 2 is the regression result of the main effect. Models 2 and 3 add the moderate variables—the executive tenure and the financing constraints. The model 4 adds the cubic of the independent variable to test whether the model is S-type. The model 5 uses the conditional mixing process to test the endogeneity of the sample [12]. It can be seen from the model 5 in Table 2 that the auxiliary estimation parameter atanhrho_12 in the estimation result is not significantly different from 0, indicating that the external search breadth is an exogenous variable, and there is no endogeneity problem in the sample. Therefore, in order to ensure the robustness of the estimation results, the estimation results of Models 1–4 should be used.

Model 1 in Table 2 shows that the external search breadth at 5% statistical level significantly promotes process innovation performance, and the square of the external search breadth significantly negatively affects process innovation performance at the 10% statistical level. H1 is supported. It can be seen from Model 2 that the interaction term between the executive term and the external search breadth is significantly positive at the 1% statistical level, and the interaction term between the executive term and the external search breadth squared term is significantly negative at the 5% statistical level, indicating that the executive tenure has a significant positive moderating effect. H2 is supported. It can be seen from Model 3 that the interaction term between the financing constraint and the external search breadth is not significantly negative, and the interaction term between the financing constraint and the square of the external search breadth is not significantly positive. H3 is not supported.

5 Inverted U-shaped Test

It can be seen from the model 4 in Table 2 that after adding the cubic of the outer search breadth of the independent variable, the cubic coefficient is not significant, indicating that there is no S-type relationship between the external search breadth and the process innovation performance. Then a three-step inverted U-shaped test is performed. The specific results are shown in Table 3.

The models (1) and (2) in Table 3 correspond to the inverted u-type test of the models 1 and 2 in Table 2, that is, the inverted u-type test for the hypotheses H1 and H2. It can be seen that the inverted U-applicability test in Model 1 is significant at the statistical level of 10%, and the low-end slope of the independent variable is 0.278, which is significantly positive at the 10% statistical level, and the high-end slope is -0.567 , which is significant at the 5% statistical level. The turning point 1.371 is within the 90% confidence interval of the independent variable. Similarly, the inverse u-type applicability test in Model 2 is significant at the 5% statistical level, the low-end slope of the independent variable is 0.368, which is significantly positive at the 5% statistical level, and the high-end slope is -1.275 at the 1% statistical level. The turning point of 0.895 is within the 90% confidence interval of the independent variable.

Table 3. Inverted u-type test

variables	(1)	(2)
Procb	0.640**	0.720**
	(1.99)	(2.41)
Procb ²	-0.265^*	-0.412^{***}
	(-1.89)	(-2.64)
X _L slope	0.278	0.368
	(1.645)*	(2.017)**
X _H slope	-0.567	-1.275
	$(-1.846)^{**}$	$(-2.384)^{***}$
Appropriate U test	1.64^*	2.02^{**}
	[0.050]	[0.022]
Turning Point	1.317	0.895
90% confidence interval	[-0.019, 2.300]	[0.376, 1.349]

Note: The same as Table 2

To further prove whether the moderating effect of the manager’s tenure on the external search breadth and the process innovation performance is as expected, we draw the moderating effect diagram, and the result is shown in Fig. 1. It can be seen from Fig. 1 that when the senior management term is high, the relationship between the external search breadth and the process innovation performance is steep. When the senior management term is low, the relationship between the external search breadth and the process innovation performance is relatively flat. So H2 is further supported.

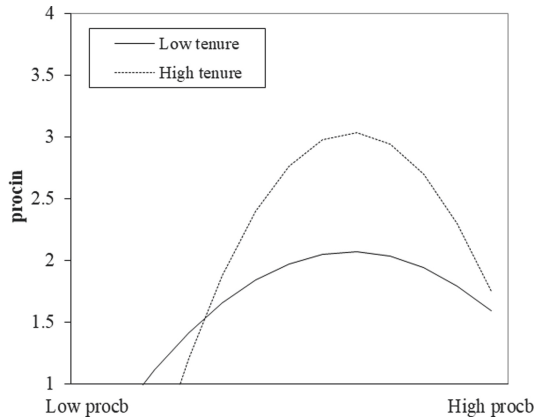


Fig. 1. The moderating effect of executive tenure

6 Robustness Test

This paper also uses the basic model Poisson distribution model to regress the sample, and further eliminates the interference of the sample heteroscedasticity. The report results are shown in Table 4. Model 6 is the regression result of the main effect. Models 7 and 8 are the regression results after adding the moderate variables—the executive term and the financing constraint. And the model 9 is the regression result after adding the cubic of the external search breadth of the independent variable. From Model 6 we can see that H1 is further supported. From Model 7 we can see that H2 is further supported. It can be seen that the inversion u-type suitability tests of Model 6 and Model 7 are robust. From Model 8 we can see that H3 is not supported.

Table 4. Poisson regression results.

Variable	6	7	8	9
Procb	0.637*	0.697**	0.54	-0.523
	(1.8)	(2.29)	(0.88)	(-0.01)
Procb ²	-0.298*	-0.456***	-0.23	1.332
	(-1.69)	(-2.64)	(-0.66)	-0.01
Procb ³				-0.509
				(-0.01)
Procb*Tenure		0.120**		
		-2.44		
Procb ² *Tenure		-0.073**		
		(-2.40)		

(continued)

Table 4. (continued)

Variable	6	7	8	9
Procb*Finance			-0.192	
			(-0.34)	
Procb ² *Finance			0.069	
			(0.24)	
LR chi2	85.85***	89.13***	86.09***	86.02***
Pseudo R2	0.112	0.116	0.112	0.112
N	395	395	395	395
X _L slope	0.285	0.373		
	(1.467)*	(1.606)*		
X _H slope	-0.570	-1.248		
	(-1.340)*	(-1.648)*		
Appropriate U test	1.34*	1.61*		
	[0.091]	[0.055]		
Turning point	1.330	0.921		
90% confidence interval	[-0.019, 2.300]	[0.376, 1.349]		

Note: The same as Table 2

7 Conclusions

With the advent of the era of big data, this article starts from the perspective of knowledge search channels, this paper selects the 2014 World Bank survey data of private enterprises in India, based on the integration perspective of organizational learning theory and attentional view, examines the inverted u-type relationship between external search breadth and process innovation performance, and the moderating effect of attention distribution process. We found that, initially, the external search breadth of the enterprise positively affects the process innovation performance. When the external search breadth reaches a certain level, it has a negative impact on the process innovation performance. The enterprise executive term positively moderates the external search breadth and the process innovation performance.

Through this research, this paper draws the following enlightenments: 1) Enterprises should follow the market trend, learn and absorb external knowledge, and reasonably control the external search breadth. Enterprises should appropriately control the external search breadth, effectively avoiding the negative effects brought by extensive knowledge search effect. 2) Enterprises should constantly improve relevant management systems and extend the term of talented executives. As an important part of human resources, managers, especially executives, have become increasingly prominent in the decision-making of modern organizations. 3) Enterprises should actively explore and discover other factor structures that affect the attention distribution of enterprises, find external knowledge that matches existing knowledge in enterprise process innovation, rationally

allocate attention, rationally manage external relations, and improve the benefits brought by external knowledge.

References

1. Katila, R., Ahuja, G.: Something old, something new: a longitudinal study of search behavior and new product introduction. *Acad. Manag. J.* **45**(6), 1183–1194 (2002)
2. Laursen, K., Salter, A.J.: The paradox of openness: appropriability, external search and collaboration. *Res. Policy* **43**(5), 867–878 (2014)
3. Laursen, K., Salter, A.: Open for innovation: the role of openness in explaining innovation performance among U.K. manufacturing firms. *Strateg. Manag. J.* **27**(2), 131–150 (2006)
4. OECD: Innovation Strategy: Defining Innovation (2015). <http://www.oecd.org/site/innovationstrategy/defininginnovation.htm>
5. Ocasio, W.: Attention to attention. *Organ. Sci.* **22**(5), 1286–1296 (2001)
6. Terjesen, S., Patel, P.C.: In search of process innovations: the role of search depth, search breadth, and the industry environment. *J. Manag.* **43**(5), 1421–1446 (2017)
7. Stevens, R., et al.: Attention allocation to multiple goals: the case of for-profit social enterprises. *Strateg. Manag. J.* **36**(7), 1006–1016 (2015)
8. Adner, R., Levinthal, D.: Demand heterogeneity and technology evolution: implications for product and process innovation. *Manag. Sci.* **47**(5), 611–628 (2001)
9. Haans, R.F., Pieters, C., He, Z.L.: Thinking about U: theorizing and testing U- and inverted U-shaped relationships in strategy research. *Strateg. Manag. J.* **37**(7), 1177–1195 (2016)
10. Roodman, D.: Fitting fully observed recursive mixed-process models with *Cmp. Stata J.* **11**, 159–206 (2011)
11. Zhu, J.X., Wu, P., Chen, M.C., Kim, M.J., Wang, X.Y., Fang, T.C.: Automatically processing IFC clipping representation for BIM and GIS integration at the process level. *Appl. Sci.* **10**(6), 2009 (2020)
12. Zhang, T., et al.: Phosphorus recovered from digestate by hydrothermal processes with struvite crystallization and its potential as a fertilizer. *Sci. Total Environ.* **698**, 134–240 (2020)