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Knowledge Sources and Manufacturing Enterprise's Technological Innovation

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ABSTRACT

This paper uses the questionnaire data of the World Bank's China Enterprise Survey 2012 to establish a Logit model to empirically study the relationship between knowledge sources and technological innovation in Chinese manufacturing enterprises. The results show that although internal and external knowledge has a positive effect on enterprise technological innovation in general, there are significant differences when taking the types of innovation, subject characteristic and the types of cooperation into consideration. From the current development stage of China's manufacturing enterprises, external knowledge sources, external enterprise knowledge subjects, and employee knowledge have a more positive effect on technological innovation, which also shows that the role of technical employees on technological innovation has a significant threshold effect, and only after a certain degree of accumulation can internal technical employees have a more significant positive effect on technological innovation.

KEYWORDS

Internal knowledge; External knowledge; Product innovation; Process innovation; Manufacturing enterprise

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1. Introduction

According to the data, the proportion of R&D expenditure of Chinese enterprises in the whole society has increased from 61% in 2002 to 74% in 2011, which is higher than that of the US, UK and France, and slightly lower than that of countries such as South Korea and Japan (Lv, 2013). However, the situation that the manufacturing industry still relies heavily on imports and foreign-owned enterprises for core technologies, basic and critical software and hardware facilities has not been fundamentally changed (Huang & Li, 2015), and it is still a net importer of technology in China. This indicates that a deficiency in the innovation capacity of Chinese manufacturing companies.

Technological innovation in manufacturing enterprises is one of the most difficult areas among many innovations. With the deepening development of science and technology and the refinement of production processes, the complexity of the technological innovation process has greatly deepened, and the general knowledge and tacit knowledge sources required for enterprise innovation face more complex interactions. It is necessary to study the influence of different knowledge sources on technological innovation in manufacturing enterprises in China from the perspective of knowledge subjects, and analyze the roles and functions of different subjects inside and outside enterprises in different types of innovation in enterprises.

The technological innovation route includes three related links, the upstream link of scientific discovery and knowledge innovation, the midstream link of scientific knowledge incubation into new technologies, and the downstream link of new technology adoption (Hong, 2012). In purely technological terms, the Oslo Manual defines technological innovation as "the implementation of a new product (good or service) or process". It follows that technological innovation emphasizes the ultimate application of knowledge. At present, the literature on the relationship between knowledge and technological innovation in manufacturing enterprises can be mainly divided into three types. The first type of research believes that the internal knowledge of the enterprise is mainly affected by the human capital owned by the enterprise (Iyigun and Owen, 1998), focusing on the impact of the stock and increment of human capital on innovation. In terms of stock, the research has focused on the educational background and experiential knowledge of managers and employees. Most empirical researches show that the number of years of education or level of education has a positive effect on the innovation activities of firms, both for managers and employees (Scherer and Huh, 1992; Lynskey, 2004; Marvel and Lumpkin, 2007; Wu & Liu, 2009), but there are exceptions (Sun & Jin, 2014; Nazarov & Akhmedjonov, 2012).

Research on experiential knowledge suggests that for managers, general industry background and experience has a weak effect on innovation, with only engineering, marketing and R&D work experience directly related to innovation having a positive effect on innovation (Marvel & Lumpkin, 2007; Robson et al, 2012). Research on incremental human capital (investment) has focused on the training of general employees, and the vast majority of findings also confirm the positive impact of training on enterprise' innovation output (Sun & Jin, 2014; Laursen & Foss, 2004; Wang et al, 2015). The second type of research is based on an open innovation perspective and examines the role of external knowledge acquisition by firms. A large number of literature have examined the significant role of research institutions, collaborative development between firms, and industry-university-research alliances between university-enterprise in the innovation process of firms (Kaufmann & Tödtling, 2001; Becker & Dietz, 2004; Liu & Kan, 2011). Researches have also further analyzed the significant impact of vertical alliances with suppliers on firm innovation (Luzzini et al, 2015), but the literature also finds that joint development between government and financial institutions does not have a significant impact on firm innovation (Liu & Kan, 2011). The third type of research focuses on the interplay of internal and external knowledge and its role in innovation. Laursen & Salter (2006) found that absorptive capacity, as measured by R&D intensity, has a significant moderating effect on external knowledge and firm innovation performance using firm data from the U.K. innovation survey. Ferreras-Mendez et al (2015) extended absorptive capacity from unidimensional (R&D intensity) to multidimensional (awareness, absorption, maintenance, activation, transformation and application) at the empirical level, reconfirming the findings of Laursen & Salter (2006) by constructing structural equation models using data from Spanish biotechnology companies. They found that absorptive capacity has a moderating effect on the relationship between depth of knowledge sources and innovation performance.

This paper argues that there are two key problems with the above literature: (i) corporate innovation may be the result of a combination of internal and external knowledge, but current research is more limited to unilateral knowledge sources; and (ii) the existing literature does not distinguish between product innovation and technological innovation in the analysis of impact, and in fact these two types of innovation differ significantly between different enterprises (Zhang & Zheng, 2013). Using questionnaire data from the World Bank's China Enterprise Survey 2012, this article empirically investigates the relationship between knowledge sources and enterprise technological innovation, based on internal and external knowledge sources, with the perspective of internal knowledge source subjects, external knowledge source subjects and types of technological innovation. The next part of the article is organized as follows: Part 2 is the theory and hypothesis, which presents the research hypothesis and framework of the paper based on the theory. Part 3 is the research design, which introduces the data sources, variable selection and model construction of the empirical study. Part 4 analyses the empirical results. Finally, the article concludes in Part 5 with a summary of the whole article and relevant recommendations.

2. Theory and Hypothesis

2.1. Internal Knowledge and Corporate Innovation

The accumulation and production of internal knowledge in an enterprise mainly depends on the human capital owned by the enterprise (Iyigun & Owen, 1998). The human capital of an enterprise is the sum of knowledge, experience and skills possessed by all individuals in the enterprise in economic activities (Suramaniam & Youndt, 2005). For innovation, not only does it require better understanding, judgement and execution in the innovation decision-making process, but it also requires the contribution of various levels of specialized skills to the formation of the final outcome of the innovation, so that technological innovation in a company is in fact the ultimate synthesis of various human capital within the enterprise. Enterprise managers with high human capital are more likely to accept new things and make better decisions; employees with high human capital attributes accelerate and creatively apply new knowledge in production; and high-quality and well-trained R&D staff accelerate and facilitate the achievement of innovative outcomes (Ballot, 2001; Winne & Sels, 2010). From this point of view, any employee of the enterprise may become an active promoter of innovation. Therefore, it is necessary to fully tap the innovation potential of different individuals within the company, so that the human capital attached to the individual can be fully utilized, and then provide the greatest possibility for the transformation of knowledge into commercial results. (Hypothesis 1)

Hypothesis 1: Enterprise internal knowledge has a positive effect on innovation output.

There is also heterogeneity in human capital within companies. Factors such as the educational background and work experience of different employees contribute to the heterogeneity of human capital stock. Related studies have shown that even employees with the same individual characteristics have varying productivity depending on the scenario and position they hold (Liu et al, 2015). The heterogeneity of human capital reflects the differences in the impact that the knowledge of different human capital subjects may have on innovation. The influence of managers on the innovation activities of companies is mainly reflected in their decisiveness when making innovation decisions, i.e. their influence is mainly reflected in their positive impact on the innovation activities of companies. Employees are the direct participants in innovation activities, and in particular in innovation outputs, and their understanding, level of knowledge and technical competence often have an important influence on the real realization of the transition from knowledge to innovation. However, the role of the two in technological innovation varies in different stages of development. When firms are in the process of technological imitative innovation, managerial knowledge plays a smaller role in innovation, due to the less uncertainty of technological innovation; conversely, when technologies are in the process of developmental innovation, managerial knowledge plays a larger role in innovation. Therefore, this paper argues that the level of knowledge within the firm has a positive impact on innovation output. Looking further, there is a difference between knowledge from managers and employees on the innovation output of the firm (Hypothesis 2).

Hypothesis 2: In terms of types, the knowledge of managers and employees has different effects on the innovation output of enterprises.

2.2. External Knowledge and Enterprise Innovation

With the increase in the complexity of technological innovation and the deepening of the variability of the market environment, the difficulty for enterprises to achieve innovation by utilizing internal resources and their own capabilities has been greatly enhanced. The enhanced mobility of labor force, the continuous expansion of venture capital scale and the wide dissemination of knowledge among departments make enterprises no longer rely solely on their own capabilities to innovate (Vrande et al, 2009), and continuous mutual exchanges and learning with neighboring organizations have become an effective means of innovation (Vegajurado et al, 2009), so external knowledge has become an important source of corporate innovation activities, and companies are paying more and more attention to establishing external knowledge channels to promote the inflow of external knowledge. Collaboration with external knowledge bodies is a proven approach. External knowledge subjects mainly include competitors, supply and demand parties, government departments, research and consulting institutions, etc. Existing studies have shown that enterprises tend to cooperate with the above external subjects to obtain innovative resources (Chen & Ye, 2013), and integrate internal and external resources to promote their innovation performance. (hypothesis 3)

Hypothesis 3: Enterprise external knowledge has a positive effect on innovation output.

Research institutions such as universities are generally considered to produce basic knowledge, while external companies produce applied knowledge. For companies, the process of successfully turning knowledge into commercial results for profit is the source of their innovation, and this process requires more applied knowledge. In addition to the discussion of technological innovation, this paper believes that knowledge from enterprises may be more popular with enterprises. Therefore, compared with research institutions such as universities, enterprises prefer to cooperate with other enterprises, and invest more in the cooperation process, which in turn results in a fuller inflow of knowledge. Therefore, this paper argues that external knowledge sources have a positive effect on corporate innovation output. Further, knowledge from other firms has a greater impact on firm innovation output than knowledge from universities (hypothesis 4).

Hypothesis 4: In terms of types, knowledge from other enterprises has a greater impact on enterprise innovation output than knowledge from research institutions.

2.3. Internal Knowledge, External Knowledge and Enterprise Innovation

Although the important role of internal and external knowledge on enterprise innovation has been emphasized by scholars, there is no consensus on the relative status of the two and their role in the innovation process. A traditional view holds that internal knowledge still plays a dominant role in corporate innovation activities, and external knowledge plays a very limited role (Freel, 2003). Another point of view is that as the importance of external knowledge increases, internal knowledge and even internal R&D institutions are no longer an important source of knowledge for enterprises (Chesbrough, 2003). From a more comprehensive point of view, external knowledge and internal knowledge are complementary to each other: on the one hand, the accumulation of internal knowledge can improve the ability of enterprises to acquire, absorb, transform and apply external knowledge; on the other hand, the inflow of external knowledge enables the dissemination of new ideas and new knowledge within the enterprise, and promotes the integration and intersection of knowledge, thus making it possible for knowledge to be transformed into innovative business results. In this process, the "absorptive capacity" of the enterprise plays a crucial role. Some scholars believe that "absorptive capacity" has a moderating effect on the relationship between external knowledge and enterprise innovation (Zhang & Zheng, 2013; Subramaniam & Youndt, 2005).

The moderating effect of absorptive capacity on external knowledge and innovation performance reflects that internal and external knowledge are not independent of each other, and the impact on enterprise innovation may be interdependent. Existing knowledge base and efforts to expand technological capabilities are two key factors of absorptive capacity (Kim, 1999). From the existing knowledge base, internal knowledge has been mastered by the enterprise, and external knowledge flows into the enterprise and then becomes the knowledge of the enterprise relying on the knowledge circulation channel established by the enterprise. External knowledge first needs to be absorbed by the internal knowledge subject of the enterprise, and then transformed by the internal knowledge source subject into innovative output external knowledge flowing into the enterprise through the innovation process. There may be knowledge dissipation in this process, and its value is not fully applied to the firm's innovation. In terms of efforts to expand technological capabilities, internal efforts (e.g. R&D activities, training, etc.) further expand the firm's internal knowledge base and facilitate the exchange of internal knowledge subjects, thus contributing to firm innovation. External efforts (e.g. searching for external information and establishing cooperation channels) may be subject to the availability of external information and the willingness of external knowledge subjects. In this case, even if the firm's external efforts are greater than its internal efforts, its innovation performance may not be significantly improved. Therefore, this paper believes that the impact of external knowledge subjects on corporate innovation output is less than the impact of internal knowledge sources on innovation output (hypothesis 5).

Hypothesis 5: Compared with external knowledge subjects, internal knowledge subjects have a greater impact on corporate innovation output.

The empirical research of this paper will be based on the test of the above three hypotheses. To this end, this paper proposes its research framework (Figure 1). The source of external knowledge must first act on the internal knowledge subject of the enterprise, and then have an impact on the technological innovation in the enterprise. Therefore, as shown by the arrow in Figure 1, its effect on technological innovation will be weakened. The main body of internal knowledge directly affects the technological innovation in enterprises, so the application of knowledge is sufficient. The thickness of the arrows of employees and managers indicates that knowledge from employees plays a greater role in corporate innovation than knowledge from managers. The arrows of external knowledge sources indicate that the knowledge from other enterprises plays a greater role in enterprise innovation than the knowledge from research institutions.

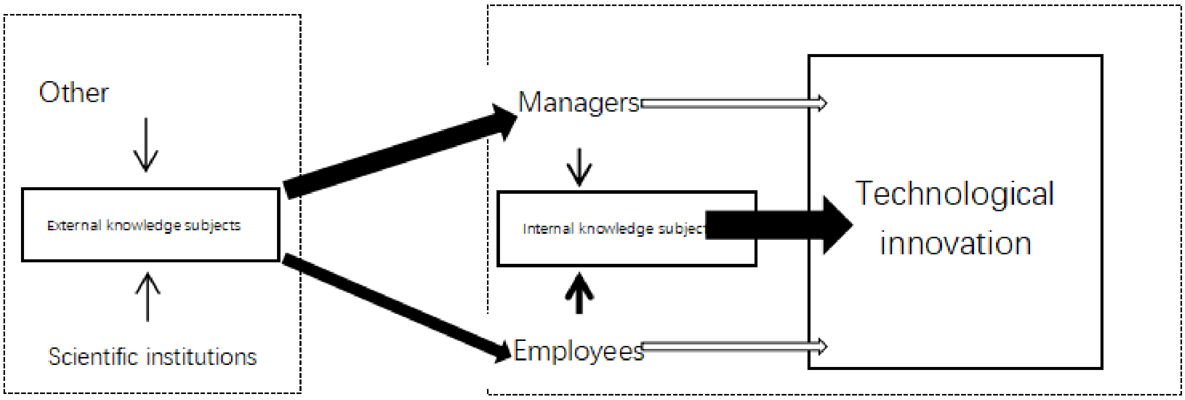

Figure 1. Internal and external knowledge and enterprise technological innovation.

3. Data, Model and Variables

3.1. Data

The sample of this article comes from The People's Republic of China 2012 Enterprise Surveys organized by the World Bank from November 2011 to February 2013. This survey is a questionnaire survey, which surveyed 2,700 private enterprises and 148 state-owned enterprises in 27 industries in 25 cities across the country through stratified sampling. The questionnaire involves the two major industries of manufacturing and service industries, and the questions involve various aspects such as internal corporate governance, production performance and business environment.

The reason we choose the data from the World Bank from November 2011 to February 2013 is that the World Bank has not organized a similar survey in China since 2012. The data is also available from the China Industrial Enterprises Database (CIED), but its survey is limited to firms' innovation inputs only and does not include knowledge sources, and the period is from 1999 to 2007. Therefore, although the data we adopted is slightly out of date, it is the most applicable data available for this research. On the other hand, according to China's statistical classification standards, industrial enterprises with less than 1,000 employees are considered MSMEs. Therefore, the enterprise samples in this research are all MSMEs. Since the internal and external environments for MSMEs have not changed significantly over the past 10 years, we believe that the heterogeneous effects of different knowledge sources on firm innovation identified in this research are still suitable for current MSMEs and are still of some relevance.

There are two main advantages of using the questionnaire data for empirical analysis. First, the sampling method of stratified sampling can meet the requirements of most econometric models for sample randomness. Second, the questionnaire was designed by experts from the World Bank who have previously conducted similar surveys in other countries, so the quality of the questionnaire can be guaranteed. This paper deals with the questionnaire data in the following ways: First, due to the lack of answers to the questions about innovation in state-owned enterprises in the questionnaire, this paper deletes the samples from state-owned enterprises. Since the questions about innovation in the questionnaire only involve the manufacturing industry, samples from the service industry are deleted in this paper. Therefore, in fact, the samples in this paper come from private manufacturing enterprises in 18 industries, and the basic information of the samples is shown in Table 1.

Table 1. Basic information on the sample.

Industry (code)	Samp le	Percentage (%)	Number of persons	Number of enterprises
Food and Beverage Manufacturing (15)	93	63.2653	Less than 20	124
Textile Industry (17)	96	62.3377	Greater than or equal to 20 and less than 100	457
Textile, clothing and apparel industry (18)	89	70.6349	Greater than or equal to 100 and less than 200	216
Manufacture of Chemical Raw Materials and Chemical Products (24)	95	66.4336	Greater than or equal to 200 and less than 300	106
Rubber and plastic products industry (25)	97	65.1007	Greater than or equal to 300 and less than 400	44
Non-metallic mineral products industry (26)	98	65.3333	Greater than or equal to 400 and less than 500	29
Ferrous metal smelting and rolling processing & non-ferrous metal smelting and rolling processing (27)	86	96.6292	Greater than or equal to 500	103
Metal Products Industry (28)	96	54.8571	Region	Number of enterprises
General Equipment Manufacturing (29)	87	57.2368	east	860
Electrical Machinery and Equipment Manufacturing & Communication Equipment, Computer and Other Electronic Equipment Manufacturing (31&32)	95	59.0062	Central	176
Transportation Equipment Manufacturing (34&35)	92	68.1481	west	43

Notes: In addition to the enterprises in the above industries, there are 55 samples from other industries, including wood manufacturing, refined petroleum, recycling and processing, recording media, precision instruments, paper making, and furniture manufacturing.

3.2. Model

The dependent variable in this paper is a binary variable. According to this characteristic of the dependent variable, the Logit model or Probit model is generally selected for empirical analysis. Compared with the Probit model, the regression results of the Logit model can be interpreted using an intuitive opportunity ratio. Therefore, this paper will choose the Logit model for empirical analysis. The specific model is:

$$ln(= \beta_0 + \sum_{i=1}^{6} \beta_i \ internal_{\ i} + \sum_{j=1}^{4} \beta_j \ external_{\ j} + \sum_{k=1}^{5} \beta_k \ control_{\ k} + u \quad (1)$$

Among them, Pinnoavtion is the probability of a certain technological innovation success, internali is the i-th internal knowledge subject variable, externalj is the j-th external knowledge subject variable, controlk is the k-th control variable, and u is a random error item.

3.3. Variables

Enterprise technological innovation can be measured from multiple perspectives, and scholars generally select corresponding indicators from two perspectives of innovation input or innovation output. Based on the perspective of innovation output, this paper conducts research on enterprise innovation from two dimensions: product innovation and process innovation. In the questionnaire, the respondents were asked: "In the past three years, which of the following types of innovation activities has this company been involved in?" When respondents answered affirmatively to any of the items "manufacturing new products or providing new services", "taking steps to increase product flexibility" and "adding new functions/features to products or services" in the past three years, the variable prod-innovation takes a value of 1, otherwise it is 0. When the respondent gave an affirmative answer to one of the items "adopted a new technology or equipment", "applied new quality control procedures in production" and "reduced production costs" in the past three years, the variable proc-innovation takes the value 1, otherwise it takes the value 0. When prod-innovation or proc-innovation takes the value 1, the variable "innovation" takes the value 1, otherwise 0. Therefore, the 3 dependent variables are all binary variables.

External knowledge is measured by the variable co-operation. When the enterprise cooperates with the supply side, demand side or other research institutions (including universities and other research institutions, consulting institutions), this variable takes the value of 1, otherwise it is 0. In order to conduct a more detailed analysis of external knowledge, the binary variables supply, client, and other-institution are respectively set to indicate that the enterprise cooperates with the supply side, the demand side, and other research institutions. When the enterprise cooperates with an external knowledge subject, the corresponding variable takes a value of 1, otherwise it is 0.

Internal knowledge consists of two parts. For knowledge from employees, this paper measures it from two aspects: short-term human capital investment and long-term human capital stock. For the former, this paper sets the variables training and tech-training. For the latter, this paper sets 3 variables: "proportion of production-worker", "proportion of technical-worker" and "employee education level education". As for the knowledge from managers, since most of the scholars' research shows that managers' industry experience has an important impact on enterprise innovation, this paper sets the variable "manager' s experience" to measure the impact of enterprise managers' knowledge on technological innovation.

Existing studies have shown that many factors at the enterprise and industry levels have a significant impact on enterprise technological innovation. Therefore, this paper controls several key influencing factors. Specifically, this paper sets export-ratio, barrier, scale, foreign-investment, industry and other variables were used as control variables in the empirical analysis.

Table 3 is the descriptive statistics of the variables. Table 3 shows that the vast majority of enterprises in the sample have practiced technological innovation, and only 25 enterprises did not report technological innovation activities. Slightly more companies have been involved in process innovation than in product innovation, and many companies have been involved in both technological innovation activities at the same time. The descriptive statistics of external knowledge source variables show that more than half of enterprises will adopt an open attitude to cooperate with external subjects in innovation activities, but at the same time, enterprises often only choose one type of external knowledge subjects for cooperation. As far as the source of internal knowledge is concerned, the vast majority of enterprises have provided training and more professional technical training for their employees. From the perspective of the internal subject of the enterprise, on average, employees have a high school education level, and enterprise managers have nearly 18 years of work experience in this industry. Finally, the descriptive statistics of the variables export-ratio and foreign-investment show that the enterprises in the sample are basically private enterprises in China, and their products are mainly oriented to the domestic market.

Table 2. Variable types, names and explanations.

Type	Variable Name	Variable Explanation
Innovation Variables	innovation	Technological innovation, take 1 when the company has product innovation or process innovation, otherwise 0
	prod-innovation	Product innovation, takes the value of 1 when the company is engaged in product innovation activities, otherwise 0
	proc-innovation	Process innovation, which takes the value of 1 when the company is engaged in process innovation activities and 0 otherwise
External Knowledge Source Variables	Co-operation	When an enterprise cooperates with external knowledge subjects
	supply	Takes the value of 1 when the firm cooperates with the supply side and 0 otherwise
	client	Takes a value of 1 when the company is working with the demand side, 0 otherwise
	other-institution	Takes the value of 1 when the company cooperates with other research institutions, 0 otherwise
Inside Knowledge Source Variables	training	1 when the company provides training for employees in general, 0 otherwise
	tech-training	1 when the company provides technical training for employees, 0 otherwise
	production-worker	Production workers as a percentage, production workers as a percentage of company employees
	technical-worker	Percentage of skilled workers, ratio of skilled workers to full-time workers in enterprises
	education	Average level of formal education of employees, measured in years
	experience	Business manager's work experience in the industry, measured in years
Control variables	export-ratio	Share of foreign exports by enterprises, from direct responses of respondents in the questionnaire
	barrier	Assumptions on the purchase of machinery, land and buildings for the current business (¥ 10000, logarithmic value)
	scale	Number of all full-time employees of the enterprise (logarithmic value)
	foreign-investment	Share of foreign capital
	industry	Industry attributes, when the enterprise is electrical machinery and equipment, communication equipment, computer and other electronic equipment, precision instrument manufacturing and other high-tech enterprises to take the value of 1, otherwise 0.

Table 3. Descriptive statistics of variables.

Variable	Average value	Median	Standard deviation	Binary response
innovation	0.9777	1.0000	0.1476	1054
prod-innovation	0.8432	1.0000	0.3638	909
proc-innovation	0.9388	1.0000	0.2397	1013
Co-operation	0.6197	1.0000	0.5044	669
supply	0.2718	0.0000	0.4472	293
client	0.3627	0.0000	0.4829	391
other-institution	0.2931	0.0000	0.4554	316
training	0.8887	1.0000	0.3147	958
tech-training	0.7653	1.0000	0.4240	825
production-worker	0.7590	0.7778	0.1116	-
technical-worker	0.4966	0.4286	0.2783	-
education	10.1300	9.0000	1.9358	-
experience	17.5300	16.0000	7.6672	-
export-ratio	14.9600	0.0000	27.3804	-
barrier	16.0800	15.1500	1.7432	-
scale	4.5340	4.5000	1.2776	-
foreign-investment	5.4790	0.0000	20.1300	-
industry	0.1760	0.0000	0.3810	190

4. Empirical Analysis

4.1. Benchmark regression

In this paper, the data is firstly regressed without distinguishing the type of technological innovation, and the results are listed in Table 4. Model 1 shows that the estimated value of the coefficient of co-operation is 1.4339 and it is significant at the 1% significance level. This shows that if the enterprise cooperates with external subjects, the occurrence ratio of technological innovation is more than 4 times that of enterprises not cooperating with external subjects. The significance and sign of the variable coefficient of the internal knowledge source of the enterprise are beyond the expectation of this paper. Variables such as training, production-worker, education, and experience were not significant at the 10% significance level. Model 2 is basically the same as Model 1, just replacing the production -worker with the technical-worker. The results show that the greater the proportion of skilled workers, the greater the degree of technological innovation in enterprises (the coefficient is 2.1815, and it is significant at the 5% significance level). Compared with the coefficient of co-operation, the coefficient of technical-worker is also larger, indicating that technical workers play a more significant role in the technological innovation in enterprises. Among other variables, the significance of training, education and experience did not change. Therefore, Model 1 and Model 2 jointly illustrate that external knowledge and technical staff have a significant positive impact on corporate technological innovation. In addition, in fact, in the two equations, the estimated value of the coefficient of training is just significant at the 15% significance level, so the impact of training will be further analyzed later. Among other control variables, the coefficients of barrier, scale and foreign-investment are significant, while the coefficients of export-ratio and industry are not significant. The coefficient shows that the technological innovation in enterprises is positively correlated with the degree of fixed capital investment, negatively correlated with the scale of the enterprise, and negatively correlated with the degree of foreign capital entry, while the degree of export and whether the industry is a high-tech enterprise do not affect the technological innovation in enterprises.

Table 4. Empirical results of technological innovation.

Independent variable	Dependent variable: technological innovation (no distinction between types of innovation)		Dependent variable: product innovation		Dependent variable: Process innovation	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	-3.0630 (2.6568)	-3.9438 (2.5070)	-6.4091*** (1.2223)	-6.3017 (1.2267)	-4.9878*** (1.5608)	-5.1675*** (1.5802)
co-operation	1.4339*** (0.4953)	1.4430*** (0.5041)	1.8939*** (0.2403)		0.5654** (0.2854)	
supply				0.1150 (0.3354)		0.6504* (0.3900)
client				1.7417*** (0.3255)		0.1875 (0.3881)
other-institution				1.0625*** (0.3433)		-0.0168 (0.3557)
training	0.7667 (0.5440)	0.7585 (0.5437)				
production-worker	2.1078 (1.9070)					
tech-training			-0.7163*** (0.2371)	-0.7141*** (0.2361)	0.7562** (0.2967)	0.7317** (0.2979)
technical-worker		2.1815** (0.8927)	-0.6845* (0.3576)	-0.7344** (0.3594)	0.6339 (0.5086)	0.6848 (0.5117)
experience	0.0082 (0.0308)	0.0033 (0.0313)	0.0404*** (0.0147)	0.0401*** (0.0145)	-0.0179 (0.0192)	-0.0180 (0.0191)
education	-0.1852 (0.1149)	-0.1779 (0.1177)	0.1887*** (0.0569)	0.1829*** (0.0577)	-0.1344* (0.0736)	-0.1350* (0.0738)
export-ratio	-0.0005 (0.0072)	0.0017 (0.0073)	0.0050 (0.0037)	0.0049 (0.0038)	0.0004 (0.0047)	0.006 (0.0048)
barrier	0.4819*** (0.1353)	0.5730*** (0.1431)	0.4601*** (0.0684)	0.4661*** (0.0688)	0.6509*** (0.0914)	0.6646*** (0.0920)
scale	-0.3511** (0.1736)	-0.3255* (0.1796)	-0.3209*** (0.0832)	-0.3342*** (0.0838)	-0.3656*** (0.1159)	-0.3634*** (0.1163)
foreign-investment	-0.0149** (0.0084)	-0.0174** (0.0083)	0.0037 (0.0065)	0.0031 (0.0067)	-0.0062 (0.0072)	-0.0066 (0.0071)
industry	0.4447 (0.5865)	0.4128 (0.5919)	-0.2238 (0.2465)	-0.2051 (0.2474)	-0.2041 (0.3297)	-0.1720 (0.3319)
Loglik	-97.2496	-94.4700	-356.7660	-354.8014	-207.8060	-207.2299
LR	35.5933***	41.1524***	222.7710***	226.7001***	81.0919***	82.2441***
McFadden R2	0.1547	0.1793	0.2379	0.2421	0.1633	0.1655
Numbers	1079	1079	1079	1079	1079	1079

*Notes: ① ***, **, * indicate significant at 1%, 5% and 10% significance levels, respectively, and the values in parentheses are the corresponding regression standard errors; ② The results of this table were generated by R software.*

4.2. Sub-effects of product innovation and process innovation

The last four columns of Table 1 show the regression results after distinguishing between product innovation and process innovation. Since Model 1 and Model 2 reflect the importance of technical knowledge to technological innovation, this paper replaces the variable training with the variable tech-training. Model 3 and Model 4 are the results obtained by regressing product innovation without distinguishing external knowledge subjects and distinguishing external knowledge subjects respectively. In comparison, the coefficient of external knowledge subjects is significantly positive, but in terms of knowledge subjects, knowledge from the supply side has no significant impact on product innovation, while knowledge from the demand side and other scientific research institutions has a significant impact on enterprise product innovation. Among them, the coefficient of client is 1.7417 and is significant at the 1% significance level, indicating that if the enterprises in the sample choose to cooperate with the demand side, the occurrence ratio of product innovation is 5.7 times that of the non-cooperation. Knowledges from other scientific research institutions also has a greater impact on enterprise product innovation, with an estimated coefficient of 1.0625. The coefficient estimates of the variables experience and education do not change significantly in both models, and positive and significant estimates indicate that the two have a positive impact on product innovation. In terms of sub-categories, the estimated value of the coefficient of the variable education is larger, so it has a greater impact on product innovation in the economic sense. However, in the two models, the coefficient estimates of the variables tech-training and technical-worker are negative, which is contrary to the empirical results of the benchmark regression in this paper, which will be further analyzed later in this paper. On the whole, for enterprise product innovation, knowledge from external subjects such as the demand side and other scientific research institutions has a positive and relatively large impact on it, and internal knowledge such as managers' experience and the education level of enterprise employees has a positive but positive impact on it. Minor impact. However, technical factors, including technical training and the proportion of technical personnel, do not have a positive impact on it.

Model 5 and Model 6 are the regression results of enterprise process innovation without distinguishing and distinguishing the types of external knowledge subjects. From the two models, it can be found that the coefficient of the variable co-operation has a significant positive effect at the significance level of 1%, indicating that external knowledge also plays an important role in enterprise process innovation. But in terms of types, unlike product innovation, cooperation with the supply side has a significant positive impact on process innovation (p value <10%, coefficient = 0.6504), while cooperation with the demand side and research institutions has a significant positive impact on process innovation. effect is not significant. The regression results of the variable tech-training show that intra-firm technical training has a positive impact on process innovation (p value <1%, coefficient = 0.7317). The coefficients of the variables technical-worker and experience are not significant, so for process innovation, there is no evidence that the experience of technical workers and managers has a positive impact on it. The coefficient of the variable education is significantly negative (p value <1%, coefficient = -0.1350), indicating that the level of employee education has an adverse effect on process innovation.

4.3. Further analysis of product innovation

The regression results of product innovation in Part 2 of this section show that technical knowledge does not have a positive effect on it, which is neither in line with theory nor in line with baseline regression results. Therefore, this paper conducts further analysis on product innovation. Model 7 adds the interaction item supply: tech-training on the basis of Model 4. The interaction coefficient is significantly positive (p value <5%, coefficient = 0.9105), indicating that although cooperation with suppliers and internal technical training have no positive impact on product innovation, providing technical training and actively cooperating with suppliers can significantly Improve the possibility of enterprise product innovation. This may indicate that product innovation requires enterprises to have the ability to integrate internal and external knowledge, and only focusing on internal knowledge or external knowledge may not achieve the desired effect. Model 8 adds the quadratic term of the variable technical-worker on the basis of Model 4. The regression results show that only when the proportion of skilled workers reaches 67% (primary term coefficient = -3.8584, quadratic term coefficient = 2.8546), the possibility of enterprise product innovation will increase with the increase of skilled workers. From the descriptive statistics of each variable in Table 2, it can be seen that the mean value of the variable technical-worker is 0.497, and the median is 0.429. Therefore, the negative impact of the proportion of skilled workers on product innovation in Model 3 and Model 4 indicates that the proportion of skilled workers in my country's manufacturing enterprises is still low and has not reached the point where it has a positive impact on product innovation.

Table 5. Further analysis of product innovation.

Independent variable	Dependent variable: product innovation	
	Model 7	Model 8
Constant	-7.2875*** (1.2028)	-5.6515*** (1.2844)
client	1.6581*** (0.3212)	1.7202*** (0.3250)
supply		0.1002 (0.3343)
other-institution		1.0848*** (0.3442)
tech-training		-0.6741*** (0.2376)
supply: tech-training	0.9105** (0.3990)	
technical-worker	-0.6299* (0.3527)	-3.8584** (1.8027)
technical-worker^2		2.8546* (1.6101)
experience	0.0461*** (0.0144)	0.0374** (0.0146)
education	0.1908*** (0.0570)	0.1919*** (0.0584)
export-ratio	0.0054 (0.0038)	0.0041 (0.0038)
barrier	0.5040*** (0.0674)	0.4583*** (0.0694)
scale	-0.3928*** (0.0815)	-0.3251*** (0.0846)
foreign-investment	0.0013 (0.0064)	-0.0032 (0.0067)
industry	-0.2459 (0.2454)	-0.1763 (0.2493)
Loglik	-362.2597	-353.1885
LR	211.7835***	229.9260***
McFadden R2	0.2262	0.2457
Numbers	1079	1079

*Notes: ① ***, **, * denote significant at the 1%, 5% and 10% significance levels respectively, and the values in brackets are the corresponding regression standard errors; ② The results in this table were generated by R software.*

4.4. Robustness Test

In this paper, OLS model and Poisson model are used to test the robustness. Model 9, Model 10 and Model 13 in Table 6 are the results of OLS regression on Model 7, Model 8 and Model 6 respectively. Due to the incomparability of the coefficients of the Logit model and the OLS model, this paper actually only cares about the relative magnitude and sign of the estimated values of the coefficients of different variables in the same model. For product innovation, it can be seen from Model 10 that the coefficients of the variables client and other-institution are still significant at the 1% significance level, and the values are also relatively large in the model. The coefficient estimation results of the interaction item supply: tech-training and the quadratic item technical-worker^2 also conform to the conclusions of Model 7 and Model 8. The same is true for process innovation. For example, the coefficient of the variable supply is significant at the 5% significance level, and most of the internal knowledge source variables are either estimated to be negative or not significant. In conclusion, the OLS robustness test results are consistent with the previous conclusions.

Table 6. Robustness tests.

Independent variable	Dependent variable: product innovation				Dependent variable: process innovation	
	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
	OLS	OLS	Poisson	Poisson	OLS	Poisson
Constant	-0.1892 (0.1212)	-0.0394*** (0.1232)	-1.4100*** (0.2601)	-1.4673*** (0.2702)	0.4527*** (0.0976)	-1.0200*** (0.2463)
client	0.1443*** (0.0190)	0.1608*** (0.0196)	0.3253*** (0.0532)	0.3220*** (0.0536)	0.0060 (0.0138)	-0.0026 (0.0530)
supply		0.0010 (0.0237)		0.0383 (0.0591)	0.0359** (0.0154)	0.1865*** (0.0498)
other-institution		0.0814*** (0.0206)		0.2373*** (0.0542)	-0.0115 (0.0158)	0.0578 (0.0491)
tech-training		-0.1006*** (0.0276)		0.2260*** (0.0641)	0.0417* (0.0216)	0.2405*** (0.0586)
supply: tech-training	0.0488** (0.0194)		0.1138* (0.0598)			
technical-worker	-0.0997*** (0.0373)	-0.4593*** (0.1775)	-0.1985** (0.0852)	-0.2118 (0.3861)	0.0221 (0.0263)	0.1864*** (0.0796)
technical-worker^2		0.3249** (0.1571)		0.0185 (0.3564)		
experience	0.0049*** (0.0014)	0.0042*** (0.0014)	0.0048* (0.0027)	0.0056* (0.0030)	-0.0010 (0.0009)	0.0011 (0.0029)
education	0.0147*** (0.0048)	0.0169*** (0.0049)	0.0208* (0.0115)	0.0174 (0.0117)	-0.0084** (0.0040)	-0.0032 (0.0112)
export-ratio	0.0007 (0.0005)	0.0006 (0.0004)	0.0005 (0.0009)	0.0004 (0.0009)	0.0001 (0.0003)	0.0001 (0.0008)
barrier	0.0640*** (0.0078)	0.0606*** (0.0077)	0.1130*** (0.0164)	0.1101*** (0.0164)	0.0411*** (0.0072)	0.1114*** (0.0154)
scale	-0.0557*** (0.0111)	-0.0498*** (0.0109)	-0.0687*** (0.0216)	-0.0680*** (0.0217)	-0.0271*** (0.0079)	-0.0580*** (0.0202)
foreign-investment	0.0001 (0.0004)	-0.0002 (0.0004)	0.0001 (0.0011)	-0.0002 (0.0011)	-0.0003 (0.0004)	-0.0001 (0.0010)
industry	-0.0306 (0.0277)	-0.0254 (0.0271)	-0.0172 (0.0600)	-0.0182 (0.0602)	-0.0176 (0.0202)	-0.0243 (0.0567)
Loglik	21.5800***	20.2523***	245.7147***	255.5788***	7.8060***	169.4355***
LR	0.1737	0.1885	0.0724	0.0754	0.0704	0.0511
McFadden R2	1079	1079	1079	1079	1079	1079

*Notes: ① ***, **, * denote significant at the 1%, 5% and 10% significance levels respectively, and the values in brackets are the corresponding regression standard errors; ② The results in this table were generated by R software.*

Model 11, Model 12, and Model 14 are the results of Poisson regression on Model 7, Model 8, and Model 6, respectively. Before estimating the model, this paper first deals with the dependent variable as follows: For a specific type of technological innovation, calculate the frequency of respondents answering yes in the questionnaire. For example, when respondents rated the company "manufacturing new products or providing new services", "taking steps to improve product flexibility" and "adding new functions/features to products or services" in the past three years In response, the variable "prod-innovation" takes the value 1. When an affirmative answer is given to one of the two items, the above variable takes the value of 2, and so on. For product innovation, the estimated results of Model 11 are consistent with expectations, indicating that the positive impact of external knowledge sources on product innovation is robust. Most of the estimated results of model 12 are in line with expectations, but the primary and secondary terms of the variable technical-worker are different from the results of the Logit model and OLS regression, and the coefficient estimates are no longer significant. According to the structure and characteristics of model variables, this may reflect that the proportion of technical employees in an enterprise is related to whether the enterprise can successfully carry out technological innovation, but not closely related to the number of successful innovations. In the results of Model 14, the coefficient of the internal knowledge source variable technical-worker becomes significant, while the estimated value of the coefficient of education becomes insignificant, and the results of the external knowledge source variable are consistent with the previous analysis. Therefore, for process innovation, the influence of external knowledge sources in our sample is robust.

4.5. Empirical conclusions

The empirical results partially support Hypothesis 1, that is, the internal knowledge of enterprises has a positive effect on innovation output, but the knowledge from employees and managers has different effects on technological innovation in enterprises. Overall, whether it is product innovation or process innovation, employees' knowledge has a more positive effect than managers' knowledge. This may be due to the fact that the innovation in most Chinese manufacturing enterprises is still dominated by imitative innovation. Although for product innovation, the analysis shows that technical training and technical staff seem to have a negative impact on product innovation, but this paper points out through further analysis that technical training needs to complement each other with external corporate knowledge to promote product innovation. The adverse impact of skilled workers reflects the fact that the proportion of skilled workers in my country's manufacturing enterprises is relatively low. When the proportion of skilled workers reaches a certain level, it will have a positive impact on enterprise product innovation. However, the empirical results reflect that the effects of internal knowledge on different types of technological innovation are not completely consistent, and the impact of internal knowledge on product innovation is more positive and robust than that on process innovation.

The empirical results support Hypothesis 2, that is, both the product innovation model and the process innovation model show that external knowledge sources have a positive effect on enterprise technological innovation, but the types of external knowledge sources are different, and the types of technological innovation affected are also different. For product innovation, cooperation with the demand side and research institutions can significantly improve its innovation level. As for process innovation, cooperation with suppliers is more conducive to enterprise innovation. This paper argues that the reason for this difference lies in the different types of technological innovation. Huang &Li (2015) emphasized that product innovation is mostly related to enterprises, universities, and R&D institutions, and process innovation is mostly related to production site exploration and experience accumulation. The conclusion of this paper further proves this point. Overall, through the coefficient estimates and statistical significance, the empirical results show that external knowledge sources have a positive effect on firm innovation, especially knowledge from external firms.

The empirical results fail to support Hypothesis 3. The empirical part shows that different enterprise internal knowledge has complex and non-uniform effects on technological innovation, while the knowledge of external subjects has a significant positive effect on technological innovation, and its coefficient estimate is larger than the former. It shows that in the samples of this paper, compared with internal knowledge sources, external knowledge sources play a more important role in enterprise technological innovation. This conclusion is in line with the theory of "open innovation". Chesbrough (2003) believed that with the promotion of the importance of external knowledge, the importance of internal R&D activities has declined. The empirical conclusions of this paper show that this assertion can even be extended to the knowledge sources within the entire enterprise. However, the functions of the external knowledge subjects are independent of each other, while the internal knowledge subjects are likely to influence each other, and their mechanism of action is relatively complicated. So far, the interrelationships of internal knowledge cannot be clearly integrated. Therefore, the thesis of this paper needs more in-depth research.

5. Summary

A large body of literature in recent years has demonstrated the important role of internal and external sources of knowledge on enterprise innovation. This paper examines the relationship between these two sources of knowledge and technological innovation in Chinese manufacturing enterprises on the basis of distinguishing technological innovation into product innovation and process innovation. This paper first proposes three hypotheses based on theory and existing empirical research, and then conducts empirical testing and analysis on them. The results show that internal employee knowledge has a more positive impact on technological innovation than manager knowledge, and external corporate knowledge has a greater impact on technological innovation than research institution knowledge. On the whole, compared with internal knowledge sources, external knowledge sources have a greater impact on enterprise technological innovation. The research of this paper mainly has the following inspirations:

First, from the perspective of internal knowledge, enterprises should focus on introducing and cultivating technical talents, and provide talent reserves for technological innovation by continuously optimizing the proportion of technical employees. This paper finds that the knowledge (especially technical knowledge) of employees in Chinese manufacturing enterprises has a positive effect on technological innovation at this stage, but due to the "threshold" effect, this positive effect has not been fully exerted. On the one hand, the increase in the proportion of technical employees can promote innovation by improving the overall education level of the enterprise. On the other hand, after crossing the threshold, it will itself have a greater impact on innovation. Furthermore, this paper finds that the simple introduction of technical personnel by enterprises only expands the knowledge base available to enterprises in a certain sense, and appropriate measures should be taken to fully release the knowledge attached to employees. Therefore, enterprises should combine the introduction of technical personnel with retraining, and fully release the knowledge owned by employees through training and cooperation with external enterprises, so as to improve the technological innovation capabilities of enterprises.

Second, from the perspective of enterprise external knowledge search, Chinese manufacturing enterprises should expand cooperation with external knowledge subjects. Quite a number of scholars believe that Chinese enterprises should solve the problem of insufficient innovation capabilities by expanding innovation investment (for example, increasing R&D investment) compared with enterprises in developed countries. The research in this paper shows that to solve the problem of insufficient innovation ability of enterprises should not only focus on the inside of enterprises, but also consider the internal and external constraints and incentive conditions faced by enterprises' technological innovation. As far as the subject of this paper is concerned, enterprises should open up internal and external knowledge by strengthening innovative cooperation with external enterprises and research institutions, and maximize the use of their knowledge base to promote technological innovation. For example, enterprises can expand R&D cooperation with external enterprises by reallocating funds, promote exchanges between internal employees and external employees of other enterprises by regularly holding inter-enterprise communication activities, and so on.

Third, enterprises should give full play to the decision-making role of managers on technological innovation. The paper does not use more variables to describe the impact of managers' decision-making behavior on technological innovation, but it does not indicate that managers' decision-making behavior lacks initiative in the process of technological innovation. In fact, in the current development stage of China's small and medium-sized manufacturing enterprises, managers are more like playing the role of follow-up technocrats, and their understanding and excavation of market demand and risk control of technological innovation are not sufficient. The research in this paper shows that managers' industry experience has a positive effect on enterprise product technology innovation, but this effect is still relatively weak. Therefore, strengthening the knowledge management of enterprise managers and fully exploiting the role of managers in technological innovation is of positive significance for the success rate of innovation.

Fourth, enterprises should deeply understand their own characteristics, and choose appropriate knowledge management strategies to promote their technological innovation capabilities. The conclusion of this paper shows that there are particularities in both knowledge and technological innovation. For a specific manufacturing enterprise, when promoting technological innovation, it is first necessary to clarify the characteristics of the enterprise itself and the characteristics of the industry, and comprehensively consider the generality of technological innovation and the particularity of the enterprise. For example, if the company is obviously engaged in a large number of product innovation activities, then the company should actively cooperate with the demand side of the product or research institutions. If the enterprise engages in a large number of process innovation activities, the enterprise should actively participate in the innovation cooperation with the supply side. Blindly imitating other corporate innovation strategies may even hinder corporate technological innovation regardless of corporate characteristics.

Fifth, the government should pay attention to the interconnectedness of enterprises while creating convenient conditions for inter-enterprise exchanges. Inter-enterprise cooperation in technological innovation is constrained by time and space. Although a large number of industrial parks have been built in China since the 1990s to reduce the spatial distance constraints of enterprises, most of them are merely piles of industrial enterprises rather than clusters of industries (Zhao & Zhang, 2008). The research in this paper shows that firms can improve technological innovation capabilities only when they cooperate with other firms that match their innovation types. Therefore, when allocating seats in industrial parks, the government should consider the relationship between technology and production among enterprises, and promote upstream and downstream enterprises in the same industry or enterprise clusters with similar technical conditions.

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Author contributions

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