Empirical study of the relations between the knowledge base and innovation performance of an economy

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Abstract

Purpose – There are many literatures on the factors that affect innovation performance, but few on the effects of knowledge base of an economy on innovation performance. One of the reason is that knowledge base is difficult to measure. Leydesdorff put forward a new method called the triple-helix model of "technology, organization, and territory" to measure knowledge base of an economy. So, the purpose of this paper is to attempt to validate empirically whether knowledge base in terms of triple-helix relations among "technology, organization, and territory" has a positive effect on innovation performance.

Design/methodology/approach – The authors developed three hypotheses on the basis of reviews, and used multiple regression models and data from the *Statistical Yearbook of China* to study empirically the relations between knowledge base of an economy, expressed in terms of the triple-helix relations among "technology, organization, and territory", and innovation performance.

Findings – Not all types of innovation performance are promoted by knowledge base in terms of the triple-helix relations among "technology, organization, and territory". The positive effect of knowledge base on patent produced as innovation performance is significant, but is not significant on technology produced and new product development. The technology level and organizational type of a region are important factors that affect patent produced and technology produced. However, their effect on new product development is not significant. "Size of enterprises" can better represent a helix of triple-helix relations than "ownership of enterprises". This means that the effect of "size of enterprises" is more direct. Medium-tech sectors are more important than high-tech sectors to patent production when the mechanism of interaction and synergy of technology, organization and territory exists.

Originality/value – This paper designs multiple regression models in terms of the triple-helix relations among "technology, organization, and territory", and helps to put forward some suggestions to enhance the innovation performance of a country or region.

Keywords Knowledge management, Innovation, China, National economy

Paper type Research paper

1. Overview and hypotheses

1.1 Innovation performance

There are many literatures on the external factors that affect innovation performance, these factors include international trade (Falvey *et al.*, 2004; Rodriguez and Rodriguez, 2005; Pla-Barber and Alegre, 2007), FDI (Blomstrom and Kokko, 1998; Feinberg and Majumdar, 2001), industrial R&D (Hall and Mairesse, 1995; Davis and Meyer, 2004;

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Kafouros and Buckley, 2008; Wang and Kafouros, 2009), and internationalization (Kafouros *et al.*, 2008).

In addition, there are flourishing researches on the firm-specific factors that affect the innovation performance. For example, Chandra and MacPherson (1994) reported that most of the innovative companies exhibit above-average research and development expenditures, as well as strong and often complex links to external sources of innovation support. Lemoine and Uenal-Kesenci (2004) discussed assembly trade and technology transfer of China and found that these outward-oriented and highly competitive industries, which are based on imported technology and foreign affiliates, seem to have had limited impact on local production and on the diffusion of technology in China's domestic industry. Bruun and Bennett (2002) discussed techno-economic security issues inherited in technology transfer from the Scandinavian and European perspective. Guan *et al.* (2006) discussed technology transfer and innovation performance with special reference to Chinese industrial firms. Their study revealed that the innovation activities in Chinese manufacturing firms could not be boosted substantially merely through the acquisition of key equipment and apparatus from abroad. Frenza and Ietto-Gillies (2009) consider two main categories of knowledge sources and their impact on the innovation performance of enterprises: own-generation through R&D versus knowledge transfers via bought-in resources for innovation purposes, external collaborations on R&D, and internal sources within the company. Although there have been many researches on external factors and firm specific factors that affect innovation performance, there have been very little literature on the effects of knowledge base on innovation performance. This paper will attempt to determine the effects of knowledge base on innovation performance.

1.2 Knowledge base of an economy

Ever since the concept of "knowledge-based economy" was written in the 1996 annual report of OECD, it has been highly emphasized by many countries, organizations, and academic institutions. However, the job of measuring it remains a difficult problem (Foray, 2004). This explains why there are few literatures on the relations between the knowledge base and innovation performance. The theoretic base of knowledge-based economy is the national innovation system. Lundvall's (1988) argument for considering the nation as a first candidate for defining innovation systems was carefully formulated in terms of a heuristics (Leydesdorff *et al.*, 2006):

> The interdependency between production and innovation goes both ways. [. . .] This interdependency between production and innovation makes it legitimate to take the national system of production as a starting point when defining a system of innovation (Lundvall, 1988).

The choice of the nation as a frame of reference enables the analyst to use national statistics about industrial production and market shares, to make systematic comparisons among nations (Lundvall, 1992; Nelson, 1993), and to translate the findings into advice for national governments (Leydesdorff *et al.*, 2006). The relevant statistics have been made comparable among nations by the OECD and Eurostat (OECD/Eurostat, 1997; Leydesdorff *et al.*, 2006).

OECD and some scholars have made some researches in this field and have made some progress using national innovation systems. However, the analysis of the knowledge base of innovation systems (Cowan *et al.*, 2000) is still not sufficiently made to be relevant for the measurement of the knowledge base of an economy (David and Foray, 2002; Leydesdorff *et al.*, 2006). National innovational system places too much emphasis on the organization of institutions and economic growth, and not enough on the distribution of knowledge itself (David and Foray, 1995; Leydesdorff *et al.*, 2006). Also, knowledge is not considered as a coordination mechanism for the society, but mainly as a public or private good (Leydesdorff *et al.*, 2006).

In order to resolve these problems, Leydesdorff and Fritsch (2006), and Leydesdorff *et al.* (2006) put forward triple-helix model of "technology, organization, and territory" to measure knowledge base of an economy. This model is based on the "holy trinity" model of "technology, organization, and territory", and triple-helix model of university-industry-government relations.

The theory of "holy trinity" argues that technology, organization, and territory inter-twist with each other and overlap partially to shape a new world. This world appears in the form of relations, and develops competitive advantage when the density of the relations is materialized in the territory (Storper, 1997). In the triple-helix relations among "technology, organization, and territory", the three sources of variance (technology, organization, and territory) may reinforce one another in a configuration so that the uncertainty is reduced at the systems level; a knowledge-based order of the economy is thus shaped (Leydesdorff and Fritsch, 2006).

On the other hand, triple-helix analysis of university-industry-government networks where the institutional settings overlap with each and sometimes taking the role of the others (Etzkowitz and Leydesdorff, 1995, 1997, 1998, 2000). The correlation of the three participants is an important factor in improving knowledge production and spreading. In the course of translating knowledge into productivity, every participant interacts with each other and promotes innovation spirally uprising (Etzkowitz and Leydesdorff, 1995).

The reasons why triple-helix model chooses technology, organization, and territory as the research object of knowledge base are as follows: the division of innovational labor mainly happens at the level of nation or region. That is knowledge is accumulated in national and regional systems (Lundvall, 1992; Nelson, 1993). Also, considerable part of knowledge exchange relations is constrained geographically (Marshall, 1920). In addition to the geographical distributions, technology is crucial for the strength of innovative system (Fritsch, 2004). After all, knowledge accumulation and innovation are mainly embodied through technological level. Besides, the geographical distributions and technological level, division of labor at different level of an organization is considered as a third determining factor influencing the knowledge base (Storper, 1997).

Leydesdorff and Fritsch (2006) and Leydesdorff *et al.* (2006) put forward a method for measuring the knowledge base of an economy in terms of the triple-helix relations among "technology, organization, and territory". This method is called triple-helix arithmetic or TH arithmetic for convenience (Leydesdorff and Fritsch, 2006; Leydesdorff *et al.*, 2006). Using TH arithmetic, Leydesdorff *et al.* (2006) measured the knowledge base of the Netherlands economy. Leydesdorff and Fritsch (2006) measured the knowledge base of German economy. Lengyel and Leydesdorff (n.d.) measured the knowledge base of Hungarian economy. However, their conclusions are in contrast to that of most scholars and our observations because they argue that medium-tech sectors contribute more to knowledge base of an economy than high-tech ones (Leydesdorff and Fritsch, 2006; Leydesdorff *et al.*, 2006).

Triple-helix model of “technology, organization, and territory” not only provides an innovative methodology for measuring knowledge base of an economy, but also explains the configuration of knowledge and dynamics of innovation system evolution.

1.3 Hypothesis

Our hypotheses investigate the relations between the knowledge base and innovation performance. From our observations and practices, good knowledge base can contribute to innovation performance of a region or nation. For example, the innovation performance of an industrial estate nearby a university is better in general, because the presence of the university enhances the knowledge base of the area. So, we put forward the first hypothesis:

> *H1*. The knowledge base of economy based on triple-helix relations among “technology, organization, and territory” has a significant positive effect on the innovation performance.

There are three models of relations of “university, industry, and government”; they are a “laissez-faire” model, an etatistic model, and a triple-helix model, respectively. For example, the innovation model of countries where most enterprises are state-ownership enterprises may be considered as an etatistic model. The effect of “ownership of enterprises” originates from the system’ function, the system is the external environment that affects knowledge base and innovation. So, “ownership of enterprises” also influences the knowledge base of an economy based on triple-helix relations among “technology, organization and territory”. In the triple-helix model of “technology-organization-territory”, “size of enterprises” is used as a proxy for organization. While “size of enterprises” can be a good standard for classifying enterprises and organizations, another standard for classifying enterprises can be the “ownership of enterprises”. So, we put forward second hypothesis:

> *H2*. “Ownership of enterprises” can be used as a proxy for an organization in the triple-helix model, and it has a significant effect on innovation performance.

Most people think that high-tech is more benefit to innovation performance than low- and medium-tech. However, this opinion is not without controversy. For example, the empirical results of Kirner *et al.* (2009) show that low-technology manufacturing firms lag behind their medium- and high-tech counterparts regarding their product and service innovation performance, to a large degree on purely definitional grounds, but that they seem to perform equally well and in some respects even better at process innovation. In the research of Leydesdorff and Fritsch (2006) and Leydesdorff *et al.* (2006), they drew a conclusion that medium-tech sectors contribute to the knowledge base of an economy more than the high-tech ones. If the *H1* is right, we can also draw a conclusion that medium-tech is more advantageous to innovation performance of a region. So, our third hypothesis is as follows:

> *H3*. The contribution of medium-tech sectors on regional innovation performance is more than high-tech’s.

In above three hypotheses, *H1* is to testify the relations between knowledge base and innovation performance, *H2* and *H3* are to testify the main factors that affect innovation performance in the knowledge base.

2. Model design and variables

2.1 Model design

This paper uses the standpoint of triple-helix relations among "technology, organization, and territory" to build econometric models. The main idea is that the inputs of R&D and other factors, and knowledge base expressed as the triple-helix relations among "technology, organization, and territory" codetermine the innovation performance.

In our multiple regression models, the dependent variable is innovation performance. In general, there are the product innovation and process innovation. Regarding innovation performance, the OECD's "Oslo Manual" (OECD, 1992) proposed eight innovation performance measurements for other researchers to analyze the performance of technological innovation in an innovation survey. These indicators are as follows (Chien *et al.*, 2010):

(1) number of incrementally innovative products introduced in the last three years (INCRPROD);

(2) number of radically innovative products introduced in the last three years (RADIPROD);

(3) number of new innovative manufacturing processes introduced in the last three years (INNOPRON);

(4) number of innovative manufacturing processes introduced in the last three years (INNOPROI);

(5) percentage of current sales due to incrementally innovative products introduced in the last three years (SALEINCR);

(6) percentage of current sales due to radical innovative products introduced in the last three years (SALERADI);

(7) the number of R&D employees in the last three years over current total number of employees (RDEMPLYE); and

(8) number of patents acquired in the last three years (PATENTS).

However, data on these indicators are difficult to collect; especially the statistical data on innovation is incomplete in China. On the basis of accessibility of data, we choose three indicators as a measure of innovation performance of a region. They are "number of patents granted," "number of technology produced," and "number of new product development", respectively.

Triple-helix structure of "technology, organization, and territory" is considered as knowledge base. So, the independent variables should include factors of technology, organization and territory. However, this paper studies cross-section data of Chinese various provinces, which actually has embodied the setting of geography or territory to some extent. This means that the factor of geography need not appear in the independent variables. Also, in this paper, the authors use Leydesdorff' method in choosing variables of technology and organization. We use the number of medium- and high-tech enterprises to represent technology, and the number of large-, medium-, and small-sized enterprises to represent organization. The reason why low-tech enterprise is ignored here is that, doing so can help to avoid multicollinearity effectively. In order to test *H2*, some variables about ownership of enterprises should be given. These variables are the number of state-owned enterprises, private-owned enterprises, and joint ventures.

The triple-helix relations among "technology, organization, and territory", R&D expenditures and other factors such as the quality of human resource, the quantity of human resource are important factors and should be included in regression model. However, the data for other factors such as the quantity and quality of human resource are not easy to obtain. In order to avoid the problem of omitted variables bias as soon as possible, lagged-1 dependent variable is added in regression model as one of the independent variables.

In order to make the idea of synergy and symbiosis of triple-helix structure embodied in regression model, the paper uses interaction terms of technology and organization variables. However, these interaction terms have some limitations as it only embodies the idea of synergy and symbiosis of triple-helix structure to some extent. In the regression models, "Patent" means "number of patents granted," "TechN" means "number of technology produced," "NewPK" means "number of new product development," "R&DExp" means "R&D expenditures," "HighT" means "number of high-tech enterprises," "MediumT" means "number of medium-tech enterprises," "StateE" means "number of state-owned enterprises," "JointvE" means "number of joint venture enterprises," and "LargeE" means "number of large-size enterprises".

2.2 Variables and data

The data of dependent and independent variables come from *Statistical Yearbook of China*, 2007, *High-tech Statistical Yearbook of China*, 2007, and statistical yearbook of every province in 2007. The geographical territory studied in this paper is that of China. Data for 22 provinces, four municipality cities, and five autonomous regions, except Hong Kong, Macao and Taiwan are used. So, there are 31 samples.

In the aspect of industrial technology, we use the regulations of OECD (2003) about industrial technology to classify the industry of China (Table I). In order to predigest computation, the sectors of medium-high-tech and medium-tech are united into the sectors of medium-tech. Since some of the data for tertiary industry are scarce in the *Statistical Yearbook of China*, the knowledge-intense sectors that connect closely with knowledge base are not considered. It has to be confessed that this is a limitation of this paper.

The classification of "size of enterprises" used in this paper is according to the *Statistical Yearbook of China*. This is shown Table II.

3. Result of regression analysis and explanation

3.1 Using "number of patents granted" as dependent variable

Through the analysis of regression models, the result of Table III is achieved. As we can see from Table III, the test of heteroscedasticity of linear model uses BP test, nonlinear model uses white test. Models I-IV are homoskedastic by test, and may directly use OLS test. However, Models V and VI are heteroscedastic by test, and should use Robust test.

Test-1. In test-1, *H1* is tested. This test can be done through comparing the significance of coefficient estimates of models I and II without interaction terms, and models V and VI with interaction terms. The coefficient estimates of medium-tech and high-tech enterprises are not statistically significant in models I and II. Only the coefficient estimates of large-sized and medium-sized enterprises are statistically significant. In models V-VI, the coefficient estimates of most independent variables are very statistically significant. Moreover, some independent variables, like R&D

High-tech manufacturing	Medium-tech manufacturing	Low-tech manufacturing
1. Manufacturing of aviation and spacecraft	1. Manufacture of electrical machinery and apparatus	1. Manufacturing of recycle
2. Manufacturing of pharmaceutical	2. Manufacture of motor vehicles, trailers, and semi-trailers	2. Manufacture of lumber, pulp and paper, and printing and publishing
3. Manufacturing of office machinery and computers	3. Manufacture of chemical products except pharmaceutical	3. Food, drink, and tobacco
4. Manufacturing of radio, television, and communication equipment and apparatus	4. Railway equipment and transport equipment	4. Textile, leather, and shoes' processing
5. Manufacturing of medical precision and optical instruments, and watches and clocks	5. Manufacture of machine and equipment	
	6. Manufacture and repair of shipping and manufacture of rubber products	
	7. Coke and petroleum refining, nuclear fuel	
	8. Other non-metal mineral	
	9. Manufacture of basic metal and processing metal	

Table I. Classification of high-, medium-, and low-tech sectors according to OECD

Index name	Unit	Small-sized	Medium-sized	Large-sized
Number of the employed	Person	300 and less	300-2,000	2,000 and more
Sales	million Yuan	30 and less	30-300	300 and more
Total assets	million Yuan	40 and less	40-400	400 and more

Source: State Statistical Bureau of China, Classification Way of Large-medium-small Enterprises in Stat. May 22, 2003

Table II. Classification of size of enterprises in China

expenditure, medium-tech enterprises, high-tech enterprises, and some interaction terms, are more economically significant. It is thus obvious that the triple-helix relations among "technology, organization, and territory" as knowledge base has a significant positive effect on patent produced.

Test-2. In test-2, tested *H2* tested. From the viewpoint of economics, large-medium-sized enterprises have more capital, and stronger human resources. So, their technology level is correspondingly higher than medium-small-sized enterprises. However, relative to different ownership of enterprises, there are generally no specific preference to high-tech and medium-tech. So, the factor "size of organization" is more suitable proxy for organization in the triple-helix model than "ownership of organization". In Table III, Models I and II are the regression models without the idea of triple-helix. Comparing these two models, we can know that the coefficient estimates of medium-tech enterprises, state-owned enterprises, private enterprises, and joint

Table III. Result of multiple regression analysis when the dependent variable is "number of patents granted"

	Model I (OLS)		Model II (OLS)		Model III (OLS)		Model IV (OLS)		Model V (robust)		Model VI (robust)	
R&DExp	−22.645	(13.436)	18.278	(11.348)	−7.766	(12.633)	−17.947	(10.816)	7.656	(8.253)	12.724***	(4.346)
HightT	11.9700*	(3.200)	2.472	(2.746)	5.878	(3.999)			2.884	(3.035)		
MediumT	0.088	(1.003)	1.201	(0.799)			0.082	(0.209)			0.539***	(0.128)
StateE	1.415	(2.889)										
PrivateE	−0.236	(0.794)										
JointvE	0.107	(0.677)										
LargeE			−57.589***	(15.668)								
MediumE			10.047***	(2.568)								
SmallE			−0.878	(0.525)								
MediumT × StateE					0.000	(0.000)						
MediumT × PrivateE					−0.000	(0.000)						
MediumT × JointvE					0.000	(0.000)						
HighT × StateE							0.005*	(0.003)				
HighT × PrivateE							0.000	(0.000)				
HighT × JointvE							0.000	(0.000)				
MediumT × LargeE									−0.002**	(0.001)		
MediumT × MediumE									0.001***	(0.000)		
MediumT × SmallE									−0.0000**	(0.000)		
HighT × LargeE											−0.028***	(0.004)
HighT × MediumE											0.005***	(0.001)
HighT × SmallE											−0.000***	(0.000)
$Patent_{t-1}$	0.445	(0.255)	−0.085	(0.221)	0.455*	(0.231)	0.754***	(0.196)	0.484*	(0.256)	0.486**	(0.186)
Constant	−810.046	(1117.713)	−345.116	(543.424)	315.387	(701.968)	707.119	(603.393)	755.667	(441.186)	−286.880	(240.211)
F	73.87		120.520		97.26		146.000		655.620		12582.120	
$P > F$	0.000		0.000		0.000		0.000		0.000		0.000	
$\chi^2(1)$	22.920		5.510		31.82		10.230					
Prob. $> \chi^2$	0.000		0.019		0.000		0.001					

Notes: Significant at: *10, **5, and *** 1 percent levels; standard deviation is in parentheses ventures are not statistically significant in Model I with different ownership of enterprises. However, the coefficient estimates of large- and medium-sized enterprises are both very statistically significant in Model II. This proves that "size of enterprises" is more suitable to explain the knowledge base of an economy than "ownership of enterprises". Models III and IV are two regression models with the idea of triple-helix. In these two models, we try to replace "size of enterprises" with "ownership of enterprises". From the statistical significance, we can deduced that "ownership type of enterprises" cannot replace "size of enterprises" as a helix of triple-helix model.

Although "ownership of enterprises" has no direct effect on patent produced and cannot become a helix, it has an indirect effect on the knowledge base. This indirect effect can be explained by triple-helix relations of "university-industry-government". The economy of China was planned economy before its reform and opening up. The enterprises and universities were planned and managed by the government. This model of innovation belongs to an etatistic model. After the reform and opening up, China gradually established socialist market economy. The intervention of government to enterprises becomes less and less. This model of innovation is in the course of transition from an etatistic model to a triple-helix model. One of the criteria of triple-helix model of innovation is the proportion of non-state-ownership enterprises in the total number of enterprises. In an etatistic model, the proportion of state-ownership enterprises is very high, but in triple-helix model, the proportion of state-ownership enterprises is relatively very low. The operation of enterprises mainly depends on the market. The government no more directly intervene in the operation of enterprises, but it has the role of building and providing a good development platform for enterprises. The government, the enterprises, and the universities equally and jointly participate in the innovation process. This strengthens the quality and density of interaction of the three participants. Although the proportion of non-state-ownership enterprises in a "laissez-faire" model is also low, this model has almost been extinct in the most countries today. Thus, the reform from the dominance of state-ownership enterprises to coexistence of multi-ownership enterprises indicates a transition of innovational model from an etatistic model to a triple-helix model to some degree. This transition will contribute to improve the density and quality of systematic cooperation. So, the effect of enterprise ownership on the accumulation of knowledge base and patent produced is indirect. With regard to the empirical study about the effect of "ownership of enterprises" on patent produced, the method of time series or panel data may be used for further analysis.

Test-3. Here, *H3* is tested. To test this hypothesis, we needed to refer to Models II, V, and VI. In Model II without the idea of triple-helix, the coefficient estimate of high-tech is bigger than medium-tech's, but they are not statistically significant. This basically shows that the viewpoint of some scholars that high-tech sectors contribute more than medium-tech on innovation performance was drawn with little consideration of the interaction and synergy of the systems. In Model V, the coefficient estimate of high-tech is not statistically significant. In Model VI, the effect of medium-tech on patent produced is 0.539, and high-tech's is 0.112. So, a conclusion can be drawn that the effect of medium-tech on patent produced is more than that of high-tech. A deeper scientific conclusion is that medium-tech sectors contribute more to patent produced when the mechanism of interaction and synergy of the systems exist. However, this trend may not be evident when the effect of this mechanism does not exist or is small.

An explanation for why medium-tech contribute more to patent produced than high-tech is that high-tech manufacturing may be more focused on the (internal) production and global markets than on the local diffusion parameters (Leydesdorff and Fritsch, 2006; Leydesdorff *et al.*, 2006).

3.2 Using "number of technology produced" as dependent variable

When dependent variable is "number of technology produced", we can see that only Model II is significant from Table IV. The technology, organization, etc. are still main factors that affect the technology produced. However, the effect of triple-helix relation on the basis of synergy is not significant. So, we cannot draw a conclusion that the knowledge base of economy based on triple-helix relations among "technology, organization and territory" has a positive effect on the technology produced.

3.3 Using "number of new product development" as independent variable

When dependent variable is "number of new product development", we can see that no one model is significant from Table V. Moreover, most independent variables are not statistically significant. Also, many independent variables are not economically significant as well. However, only "$NewPK_{t-1}$" is statistically and economically significant. This shows that the knowledge base on the basis of synergy relations does not have a significant effect on the new product development, and there are other factors that affect it. These factors may be human resources, or R&D density, etc. which are not included in our models.

4. Main conclusions and limitations

4.1 Conclusions

This paper uses multiple regression models to study the relations between the knowledge base of an economy, express in terms of the triple-helix relations among "technology, organization, and territory", and her innovation performance and draws some conclusions that are as follows:

- Not all types of innovation performance are promoted by the knowledge base in terms of the triple-helix relations among "technology, organization, and territory". The positive effect of knowledge base on patent produced as innovation performance is significant, but is not significant on technology produced and new product development. This means that patent produced needs more cooperation and synergy of different organizations and technologies.
- The technology level and organizational type of a region are important factors that affect patent produced and technology produced. However, its effect is not significant on new product development.
- "Size of enterprises" better represents a helix of the triple-helix relations among "technology, organization and territory" than "ownership of enterprises". At the same time, this means that the effect of "size of enterprises" is more direct.
- Medium-tech sectors are more important to patent produced when the mechanism of interaction and synergy of technology, organization and territory exists.

4.2 Discussion

The limitations of this paper are as follows:

Table IV. Result of multiple regression analysis when the dependent variable is "number of technology produced"

	Model I (OLS)		Model II (robust)		Model III (OLS)		Model IV (OLS)		Model V (robust)		Model VI (OLS)	
R&DExp	56.329***	(17.086)	70.696***	(8.825)	39.017**	(17.647)	58.088***	(17.364)	51.158***	(8.232)	64.511***	(5.543)
HightT	−2.134	(4.394)	−3.804*	(2.206)	4.898	(5.619)			1.757	(2.136)		
MediumT	−1.436	(1.426)	2.104**	(0.766)			−0.267	(0.389)			−0.049	(0.166)
StateE	3.672	(4.411)										
PrivateE	0.910	(1.104)										
JointvE	1.087	(0.993)										
LargeE			−89.772***	(13.288)								
MediumE			7.569***	(2.507)								
SmallE			−1.442***	(0.504)								
MediumT × StateE					0.001**	(0.000)						
MediumT × PrivateE					−0.000	(0.000)						
MediumT × JointvE					0.000	(0.000)						
HighT × StateE							−0.002	(0.005)				
HighT × PrivateE							0.000	(0.000)				
HighT × JointvE							0.000	(0.000)				
MediumT × LargeE									−0.004***	(0.000)		
MediumT × MediumE									0.000*	(0.000)		
MediumT × SmallE									−0.0000**	(0.000)		
HighT × LargeE											−0.046***	(0.005)
HighT × MediumE											0.003***	(0.001)
HighT × SmallE											−0.000	(0.000)
$TechN_{t-1}$	0.146	(0.178)	0.190*	(0.105)	0.376**	(0.163)	0.254	(0.183)	0.308***	(0.090)	0. 207**	(0.076)
Constant	165.459	(1609.587)	926.408	(392.494)	401.351	(968.205)	890.096	(1112.449)	−62.958	(358.412)	121.426	(514.875)
F	19.34		175.83		26.44		22.12		668.83		116.67	
$P > F$	0.000		0.000		0.000		0.000		0.000		0.000	
$\chi^2(1)$	23.13				21.35		25.58				5.29	
Prob. $> \chi^2$	0.000				0.000		0.001				0.021	

Notes: Significant at *10, **5 and *** 1 percent levels; standard deviation is in parentheses

Table V.
Result of multiple regression analysis when the dependent variable is "number of new product development"

	Model I (OLS)		Model II (OLS)		Model III (OLS)		Model IV (OLS)		Model V (OLS)		Model VI (OLS)	
R&DExp	0.485	(2.247)	1.867	(2.515)	3.443	(2.984)	−1.015	(3.060)	3.538	(2.943)	3.076*	(1.524)
HightT	0.095	(0.657)	0.502	(0.792)	−0.464	(1.164)			−0.255	(1.025)		
MediumT	−0.295	(0.258)	−0.059	(0.289)			−0.051	(0.076)			−0.015	(0.070)
StateE	0.977	(0.739)										
PrivateE	0.170	(0.189)										
JointvE	0.322**	(0.154)										
LargeE			−1.065	(4.663)								
MediumE			0.678	(0.867)								
SmallE			−0.038	(0.188)								
MediumT × StateE					0.000	(0.000)						
MediumT × PrivateE					0.000**	(0.000)						
MediumT × JointvE					0.000	(0.000)						
HighT × StateE							0.001	(0.001)				
HighT × PrivateE							0.000	(0.000)				
HighT × JointvE							−0.000	(0.000)				
MediumT × LargeE									−0.000	(0.000)		
MediumT × MediumE									0.000	(0.000)		
MediumT × SmallE									−0.000*	(0.000)		
HighT × LargeE											−0.002	(0.002)
HighT × MediumE											0.000*	(0.000)
HighT × SmallE											0.000	(0.000)
$NewPK_{t-1}$	1.121***	(0.085)	1.120***	(0.108)	1.080***	(0.098)	1.098***	(0.092)	1.148***	(0.097)	1.163***	(0.106)
Constant	−279.031	(294.571)	−42.441	(195.321)	17.505	(201.054)	60.444	(206.456)	−54.843	(187.713)	−70.537	(208.856)
F	152.07		124.62		159.61		169.85		156.05		0.003	
$P > F$	0.000		0.000		0.000		0.000		0.000		0.000	
$\chi^2(1)$	2.92		10.85		7.05		7.49		8.73		8.69	
Prob. $> \chi^2$	0.088		0.001		0.008		0.0062		0.003		0.003	

Notes: Significant at: *10, **5 and *** 1 percent levels; standard deviation is in parentheses

- In the design of multiple regression models, interaction terms of technology and organization cannot completely reflect the idea of synergy and symbiosis of triple-helix relations among "technology-organization-territory" because of lacking of the interaction of territory. In addition, one-fits-all regression may ignore regional differences in the stages of transitions in terms of university-industry-government relations and knowledge input-output relations. In the future, new empirical model should be explored.
- In the design of dependent variables, we choose three indicators which are "number of patents granted", "number of technology produced" and "number of new product development", respectively. No one indicator reflects process innovation. So, the more indicators on innovation performance should be considered in the future.

  In the design of independent variables, though the number of enterprises could reflect a measure of the knowledge base of region to a certain extent, it has some limitation in reflecting the quality of knowledge base. In addition, although a lagged-1 dependent variable is added in regression model as one of the independent variables which avoid the problem of omitted variables bias to some extent, some important factors such as HR and territory are at best considered in the future research.
- The problem of data and samples does exist, because we only collected 31 samples at the provincial level. So, the number of sample is relatively small. In addition, since the statistical yearbook does not contains data for small-sized enterprises with major business income less than five million Yuan, this sample reduces the actually numbers of small-sized enterprises, which will result in the problem of bias of regression models.

References

Blomstrom, M. and Kokko, A. (1998), "Multinational corporations and spillovers", *Journal of Economic Surveys*, Vol. 12 No. 3, pp. 247-77.

Bruun, P. and Bennett, D. (2002), "Transfer of technology to China: a Scandinavian and European perspective", *European Management Journal*, Vol. 20 No. 1, pp. 98-106.

Chandra, B. and MacPherson, A. (1994), "The characteristics of high-technology manufacturing firms in a declining industrial region: an empirical analysis from western New York", *Entrepreneurship & Regional Development*, Vol. 6, pp. 145-60.

Chien, S.C., Wang, T.Y. and Lin, S.L. (2010), "Application of neuro-fuzzy networks to forecast innovation performance: the example of Taiwanese manufacturing industry", *Expert Systems with Applications*, Vol. 37, pp. 1086-95.

Cowan, R., David, P. and Foray, D. (2000), "The explicit economics of knowledge codification and tacitness", *Industrial and Corporate Change*, Vol. 9 No. 2, pp. 211-53.

David, P.A. and Foray, D. (1995), "Assessing and expanding the science and technology knowledge base", *STI Review*, Vol. 16, pp. 13-68.

David, P. and Foray, D. (2002), "An introduction to the economy of the knowledge society", *International Social Science Journal*, Vol. 54 No. 171, pp. 9-23.

Davis, L.N. and Meyer, K.E. (2004), "Subsidiary research and development, and the local environment", *International Business Review*, Vol. 13, pp. 359-82.

Etzkowitz, H. and Leydesdorff, L. (1995), "The triple helix of university-industry-government relations: a laboratory for knowledge-based economic development", *EASST Review*, Vol. 14 No. 1, pp. 14-19.

Etzkowitz, H. and Leydesdorff, L. (Eds) (1997), *Universities in the Global Economy: A Triple Helix of University-Industry-Government Relations*, Cassell Academic, London.

Etzkowitz, H. and Leydesdorff, L. (1998), "The endless transition: a 'triple helix' of university-industry-government relations", *Minerva*, Vol. 36, pp. 203-8.

Etzkowitz, H. and Leydesdorff, L. (2000), "The dynamics of innovation: from national systems and mode 2 to a triple helix of university-industry-government relations", *Research Policy*, Vol. 29, pp. 109-23.

Falvey, R., Foster, N. and Greenaway, D. (2004), "Imports, exports, knowledge spillovers and growth", *Economics Letters*, Vol. 85, pp. 209-13.

Feinberg, E.S. and Majumdar, K.S. (2001), "Technology spillovers from foreign direct investment in the Indian pharmaceutical industry", *Journal of International Business Studies*, Vol. 32 No. 3, pp. 421-37.

Foray, D. (2004), *Economics of Knowledge*, MIT Press, Cambridge, MA.

Frenza, M. and Ietto-Gillies, G. (2009), "The impact on innovation performance of different sources of knowledge: evidence from the UK Community Innovation Survey", *Research Policy*, Vol. 38, pp. 1125-35.

Fritsch, M. (2004), "Cooperation and the efficiency of regional R&D activities", *Cambridge Journal of Economics*, Vol. 28, pp. 829-46.

Guan, J.C., Mok, C.K., Yam, R.C.M., Chin, K.S. and Pun, K.F. (2006), "Technology transfer and innovation performance: evidence from Chinese firms", *Technological Forecasting and Social Change*, Vol. 73, pp. 666-78.

Hall, H.B. and Mairesse, J. (1995), "Exploring the relationship between R&D and productivity in French manufacturing firms", NBER Working Papers 3956, National Bureau of Economic Research, New York, NY.

Kafouros, M.I. and Buckley, P.J. (2008), "Under what conditions do firms benefit from the research efforts of other organizations?", *Research Policy*, Vol. 37 No. 2, pp. 225-39.

Kafouros, M.I., Buckley, P.J., Sharp, J.A. and Wang, C.Q. (2008), "The role of internationalization in explaining innovation performance", *Technovation*, Vol. 28, pp. 63-74.

Kirner, E., Kinkel, S. and Jaeger, A. (2009), "Innovation paths and the innovation performance of low-technology firms – an empirical analysis of German industry", *Research Policy*, Vol. 38, pp. 447-58.

Lemoine, F. and Uenal-Kesenci, D. (2004), "Assembly trade and technology transfer: the case of China", *World Development*, Vol. 32 No. 5, pp. 829-50.

Lengyel, B. and Leydesdorff, L. (n.d.), "Measuring the knowledge base in Hungary: triple helix dynamics in a transition economy", *Regional Studies*, available at: http://www.leydesdorff.net/list.htm (in press)

Leydesdorff, L. and Fritsch, M. (2006), "Measuring the knowledge base of regional innovation systems in Germany in terms of a triple helix dynamics", *Research Policy*, Vol. 35, pp. 1538-53.

Leydesdorff, L., Dolfsma, W. and Panne, G.V. (2006), "Measuring the knowledge base of an economy in terms of triple-helix relations among 'technology, organization, and territory'", *Research Policy*, Vol. 35, pp. 181-99.

Lundvall, B.-A. (1988), "Innovation as an interactive process: from user-producer interaction to the national system of innovation", in Dosi, G., Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. (Eds), *Technical Change and Economic Theory*, Pinter, London, pp. 349-69.

Lundvall, B.-A. (1992), *National Systems of Innovation*, Pinter, London.

Marshall, A. (1920), *Principles of Economics*, Macmillan, London.

Nelson, R.R. (1993), *National Innovation Systems: A Comparative Analysis*, Oxford University Press, New York, NY.

OECD (1992), *OECD Proposed Guidelines for Collecting and Interpreting Technological Innovation Data*, Oslo Manual, OECD, Paris.

OECD (2003), *Science, Technology and Industry Scoreboard*, OECD, Paris.

OECD/Eurostat (1997), *Proposed Guidelines for Collecting and Interpreting Innovation Data*, OECD, Paris, Oslo Manual.

Pla-Barber, J. and Alegre, J. (2007), "Analysing the link between export intensity, innovation and firm size in a science-based industry", *International Business Review*, Vol. 16, pp. 275-93.

Rodriguez, J.L. and Rodriguez, R.M.G. (2005), "Technology and export behavior: a resource-based view approach", *International Business Review*, Vol. 14, pp. 539-57.

Storper, M. (1997), *Regional World – Territorial Development in a Global Economy*, Guilford Press, New York, NY.

Wang, C.Q. and Kafouros, M.I. (2009), "What factors determine innovation performance in emerging economies? Evidence from China", *International Business Review*, Vol. 18, pp. 606-16.

Further reading

Haque, I. (1995), *Trade, Technology and Competitiveness*, World Bank, Washington, DC.

Jakulin, A. and Bratko, I. (2004), "Quantifying and visualizing attribute interactions: an approach based on entropy", available at: http://arxiv.org/abs/cs.AI/0308002

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