

Research Article

Research on Co-evolution of Technological Innovation and Firm Size in a Perspective of Two-way Interaction

Li Yu and Zhang Yao

The School of Business Administration, Dongbei University of Finance and Economics,
Jianshan Street, DaLian, Liaoning, 116025, China

Abstract: The authors study the dynamic relationship between technological innovation and firm size in the two-way interaction view and built interactive evolution space between technological innovation and firm size under the multiple-mutual structural system. Based on this analytical framework, this paper explains the dynamic coordination evolution process between technological innovation and firm size. The authors give an empirical study on the relationship between technological innovation and firm size of Chinese industrial enterprises, with VAR model's generalized impulse function and variance disassemble methodology under the mutual structure logic and the empirical result indicated that firm size influence technological innovation vastly, at the same time technological innovation influence firm size too, but this influence is hysteresis; firm size have a bigger resolution to technological innovation, however, technological innovation have a smaller resolution to firm size.

Keywords: Evolution, firm size, generalized impulse function, mutual-construction, technology innovation

INTRODUCTION

The nonlinear research on the relation between technology innovation and firm size has shifted from verifying larger or smaller enterprise has more advantage in technology innovation to the establishment process of this relation from the research of Scherer (1965) and Aghion *et al.* (2001). Especially under the new economic conditions, most research cannot explain well the complex relation between technology innovation and firm size for its one-way and static causation feature. Firstly, the study on the influence of technology innovation to firm size is missed. At the age of knowledge economy, technology innovation booms, which affect firm size greatly, such as headquarters system of multinational corporations, 'large-large alliance', 'small-large alliance' and the emergence of intermediate organizations during the vague of enterprises' boundaries (Williams, 2009). Secondly, dynamic researches between technology innovation and firm size are missed. Though inverted-U theory can estimate the trend of technology innovation level, which is consulting 'optimal size' basing on analyzing advantages and disadvantages of a large or a small enterprises in technology innovation; however, it cannot explain quantitative and qualitative changes characteristics of influence of technology innovation on the firm size, technology innovation level's influence on optimal size and the interactive trend forming process of firm size and technology innovation in

different phases.

The question above-mentioned shows that the relation between technology innovation and firm size is not one decided another but a kind of mutual-construction. In order to research this interactive dynamic relation between technology innovation and firm size, we introduce a concept of mutual-construction, suggesting that the relative relation of technology innovation and firm size is phenomenon in multi-dimensional construction system in dynamic changing process. From this view, we can reflect the new characters of influential factors on relation of technology innovation and firm size in system of the 'Knowledge Economy Age' and can also get dynamic relation between technology innovation and firm size though analyzing the movement of mutual-construction system. Consequently, the frame of mutual-construction is beneficial development of existing theories can be adopted to discuss the nonlinear relation between technology innovation and firm size further.

The objective of this study is exploring the two-way dynamic relationship between technological innovation and firm size by introducing the concept of mutual structure. In order to address this concern, we will establish dynamic change model of multiple mutual structural system and study the changing process of the relationship, so as to find new features of the special factors in the knowledge economy era that influence the relationship between technological innovation and firm size in the mutual structure system.

Corresponding Author: Zhang Yao, The School of Business Administration, Dongbei University of Finance and Economics, Jianshan Street, DaLian, Liaoning, 116025, China

This work is licensed under a Creative Commons Attribution 4.0 International License (URL: <http://creativecommons.org/licenses/by/4.0/>).

Therefore, to achieve this research purpose is to develop the present theory and make contributions to further discussion on the nonlinear relation between the technological innovation and firm size.

MUTUAL-CONSTRUCTION AND INTERACTION EVOLUTION SPACE

Concept of mutual-construction: Mutual construction is a special term which is used to describe the process formed by the interaction between two objects that belongs to the interior of binary system or polyphyletic system on the evolution track of each other and it is widely used in the study on complex nonlinear relations which exist in many fields. The mutual constructions among many things are not simple combination. Mutual construction is a process on system formation or movement, the way of its construction will lead to the changes of the function and construction of the system. The appearance of mutual construction in various natural systems and social systems is not an artificial phenomenon, the coordination action and ordered activities of each parts in mutual construction are often formed by a spontaneous forms (Birkinshaw and Stephen, 2005), that is to say, it is a self-organization, mainly assumes as follows: Firstly, the process of mutual construction needs exchanges of material and energy; some constitutive elements are systems; the construction of the different systems shows that the organization is an open one (Hulin and Roznowski, 1985). Secondly, the influence of each part is not symmetrical distribution and each part constantly exchanges with the environment to change its impact (Abbate, 1999). Therefore, the 'random fluctuations' exists, although the established system is also far from the balance state (Charles, 1997). Thirdly, the constitutive elements are often not satisfying the simple linear superposition principles (Les, 2001). New situation will emerge after formation and the nonlinear mutual construction is the internal causes of systems' forming order structure.

Interaction evolution space: From the perspective of mutual construction, the goals of researches on the relation between technology innovation and firm size, firstly is to find the elements of mutual construction. For technology innovation, technology is the first essential factors. However, not every technology in economics can be developed into innovation. Freeman (1982) pointed out in *The Economics of Industrial Innovation* (corrected edition) that the technology innovation refers to the first commercial conversion of new products, new process, new systems and new equipment^[9]. He emphasized the market's decisive effect in the process when invention transformed into technology innovation, therefore, market is also an important factor in technology innovation. At the same time, Schumpeter gave 5 classic definitions on

technology innovation and he treated achieving enterprise's new organization as one of them; Christensen rose clearly when he stated the contradiction between sustaining technology and disruptive technology that the key to break through 'innovator's dilemma' was to take organization innovation before destructive technology innovation. So, organization is one of important factors in technology innovation. Tidd *et al.* (2001) introduced the relation between the enterprise technology innovation and competitive advantage from the view of strategy management and system integration. They suggested that the basic process of technology innovation was the integration process of technology, market and organizational reform. While Si (2005) used a three-dimensional coordinate system to describe the relation among technology, market and organization when he studied the management innovation. Besides that, he studied the decisive role among their interactive influence in technology innovation strategy and called it innovation space. We believe that it is a ternary mutual construction system actually.

We used a three-dimensional coordinate to establish mutual construction space which can be described by technology, organization and market (Fig. 1) to discuss the interaction evolution between firm size and technology innovation. The mutual construction of technology organization and market can form different kinds of technology innovations and firm sizes to allow us to refine the relation between firm size and technology innovation and then to find out the internal reasons of each relation forming and the evolution process among different relationships.

Technology-organization mutual construction: Christensen (1997) detailed analyzed the relation between technology paradigm changes and organized structure changes. He divided technology into disruptive technology and sustaining technology. In his view, corresponding innovation is called disruptive technology innovation and sustaining technology innovation. Disruptive technology is a breakthrough to the original technology paradigm under the success of invention, while sustaining technology is an improvement of the original technology paradigm. The development of a technology paradigm in enterprise will eventually form a technology track and this track was restricted not only by the technology physical limitation, but also by the supporting way of organization resources and management availability. Therefore, technology and organization mutual construction follows. Generally, disruptive technology innovation is often the beginning point of a new technology track, while sustaining technology is a 'direct orbit innovation' based on original technology track (Nelson and, 1982; Mark and Steven, 2001). Because leading force of destructive technology innovation is technical factors, so it can be showed the

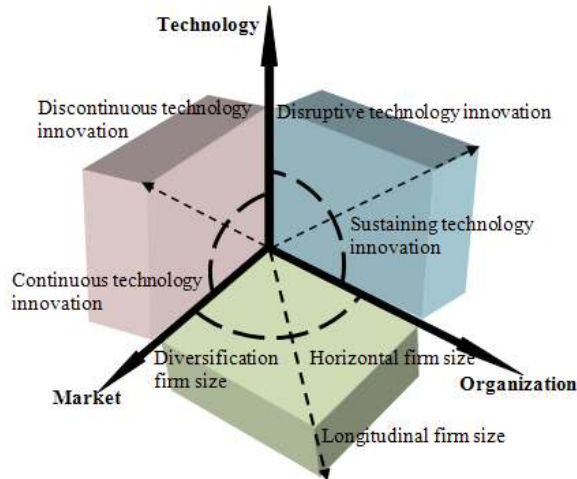


Fig. 1: Model of interaction evolution space between technology innovation and firm size based on mutual-construction

line approaching the technology coordinate axis in the picture, with the same reason, the higher the organization support be, the more effective the sustaining technology innovation will be.

Technology- market mutual construction: Though market is the decisive factor in inspection of technology innovation, it can also be divided into existing market technology innovation and creative market technology innovation. This is why existed market innovation is always called continuous technology innovation in case of improving the quality, function and reducing cost. Similarly, innovation which makes the product innovation and market innovation proceeded synchronously and created new market was called discontinuous technology innovation. The technology innovation of existing market was guided by the customers' requirements, the customers' preference and consumption custom to a large extend restrict the development of the technology. So, the factor of market plays a leading role in continuous technology innovation. One of the important contents of discontinuous technology innovation is to create new market demand by using new products, it is technology that develops and leads customers' needs. Thus, technology plays a leading role in the implement of discontinuous technology innovation.

Organization-market mutual construction: The mutual construction of organization-market is an important reason for the various firm size formations. To some extent, the changes of size reflect the contrast between the organization of enterprise's important internal and external environment and market forces, longitudinal, horizontal or diversified firm size are all influenced by the organization and market, but which way of size expansion is more effective is also being

controlled by the type of enterprise's implement technology innovation type, so, firm size is determined by mutual construction of organization and market directly and by the mutual construction of technology, organization and market indirectly.

The starting life cycle of technology is the birth of new technology. We assume it as the beginning of mutual construction space, that the new technology promotes new organization and new markets. In addition, we distinguish two pairs of four types of technology innovation categories, one pair is direct innovation and indirect innovation on the basic of the prediction of technology innovation and another pair is incremental innovation and radical innovation according to the change of technology pointing the process innovation, respectively correspond to the continues innovation, discontinuous innovation, disruptive innovation and sustaining innovation, as Fig. 2 shows.

The one leading by the new technology is discontinuous innovation and disruptive innovation (A), then the relation between market and organization will occur two kinds of change, one is new organization satisfy the new market needs, with the yield increasing the new market gradually becomes the existing market, in this process, firm size expansion mainly through expanding horizontal size (A-B); Another is in the new market, new organization's structure and function mature and perfect in development gradually and ultimately become a stable organization. Transition cost in new market is often more than in mature market, there for firm size expansion mainly through expanding longitudinal size (A-C). Firm's transformation from incremental innovation to direct innovation happens during organization maturation in the prior market, longitudinal expansion will still occur, with saturation of market capacity and subversive appearance of new technology, the focus of firm size expansion has shifted to searching for new profit growth and risk avoidance, so firm may adopt diversification firm size expansion (B-D); Firm's transformation from radical innovation to direct innovation is the process of existing organization from creating new markets to monopoly new markets, radical innovation is great subversive, new technology usually needs new organization supporting method, when appropriate organization established, purpose of firm expansion is mainly reconstructing market order through new technology, horizontal expansion for expanding marketer requirement is essential to create and cultivate new market, continuing to fight for monopoly position and ensure new technological trajectories development, firm will continue to merger and acquisition for longitudinal expansion. After obtaining monopoly position, firm will take part in diversification expansion mainly extending technology life cycle and avoiding risks (C-D). As we can see from Fig. 2, with firm

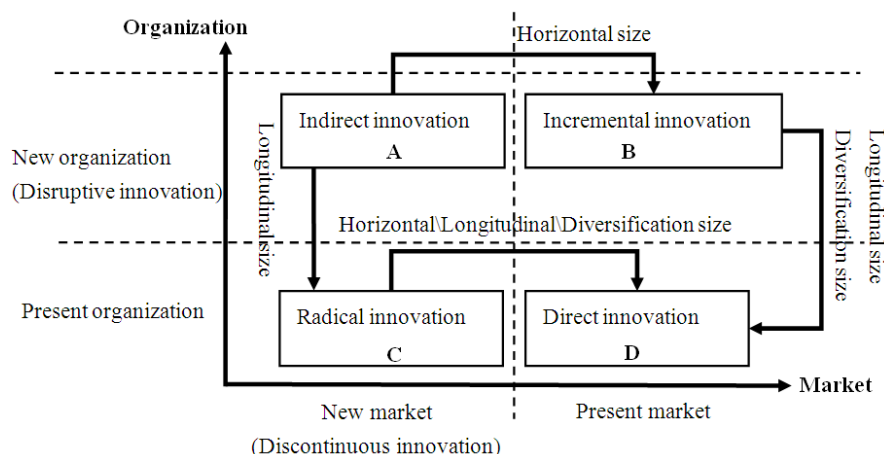


Fig. 2: Interactive evolution between technology innovation and firm size

developing from initial indirect innovation to direct innovation, firm size has great change. Firm size can not only respect that firm impacts technology innovation directly through R&D inputs, but also represent the strength of effect and counteractive effect to organization and market and then influence technology innovation indirectly. Direct innovation will encounter physical limit sooner or later, the substitution of new technology paradigm will open next technology life cycle, the interaction evolution relation will still happen in mutual construction space of technology, organization and market.

EMPIRICAL RESEARCH ON TWO-WAY FUNCTION

Here we adopt Generalized Impulse Response Function (GIRF) to eliminate the estimated bias brought by the endogenous variables and use Variance Decomposition to do some further study on the relative importance in explaining the change of each other between firm size and technology innovation.

Variable definition and impulse response result: As it is difficult to use investment methods of technology innovation to measure direct technology innovation and indirect technology innovation directly, we adopt patented features to define these two variables. No matter what type of patent is, its source can be

distinguished into service patent and non-service patent. According to our front analysis of direct technology innovation and indirect technology innovation, we take the ratio between industrial service invention patent authorization quantity and industrial firm quantity as dependent variable to measure the strength of indirect technology innovation. Considering the indirect technology innovation market-driven feature and unpredictability of indirect technology innovation evolution, we refer to the indirect technology innovation from the view of technology transaction. We believe that transference technology in technology development-type contracts is often beyond the technological paradigm of technology innovation. This is why it does not have predictability. We can use the ratio between technology transfer transaction quantity and technology development contract transactions quantity to reflect the strength of indirect technology innovation. However, when the index of technology innovation can be represented by the ratio between R&D investment and industry firm quantity, we adopt the ratio of sales income and industrial firm quantity to indicate firm size.

We use the data of Chinese industrial firms' in 1991-2005 to test the relationship. Firstly, we can obtain that this time series exists the only the cointegration relationship under the significance of 5% level by the Johansen cointegration test to satisfy the assumption which the test result of the impulse

Table 1: Analysis result of impulse response about ln (drec), ln (idrec), ln (inov) and ln (size)

Impulse response period	Ln (size) to ln (drec)	Ln (drec) to ln (size)	Ln (size) to ln (idrec)	Ln (idrec) to ln (size)	Ln (size) to ln (inov)	Ln (inov) to ln (size)
1	0.232476	0.052560	-0.038895	-0.035699	0.084935	0.079359
2	0.038455	0.066716	-0.083822	-0.059576	0.003222	0.036832
3	0.022320	0.031040	0.007099	-0.029535	0.037266	0.060206
4	-0.101417	0.033080	-0.045412	-0.048137	-0.024618	0.042022
5	0.053764	0.033899	0.017481	-0.045976	0.015000	0.058432
6	-0.015298	0.018096	-0.031973	-0.033096	-0.003054	0.031678
7	0.038833	-0.002533	0.009301	-0.007485	0.021031	0.034520
8	0.023888	0.003249	-0.027513	-0.010817	-0.001151	0.014124
9	0.075540	-0.003860	0.002482	0.004302	0.021875	0.013791
10	0.004183	-0.009804	-0.022632	0.010173	0.002039	-0.002007
total	0.293021	0.215307	-0.213884	-0.255846	0.156545	0.0368957
Impulse response curve	N Model	Linear (↓)	N Model	Linear (↑)	N Model	Inverted-U Model

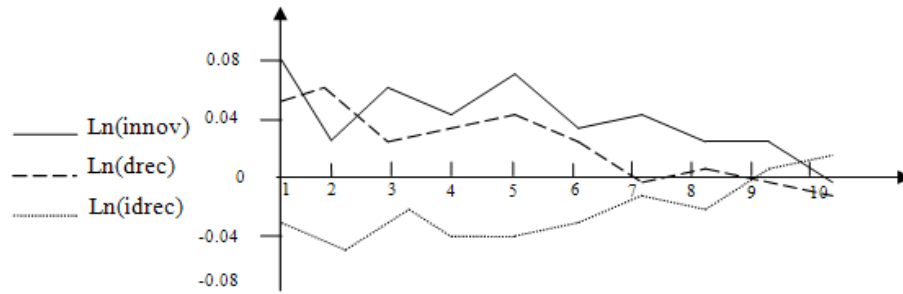


Fig. 3: Technology innovation impulse response track on firm size

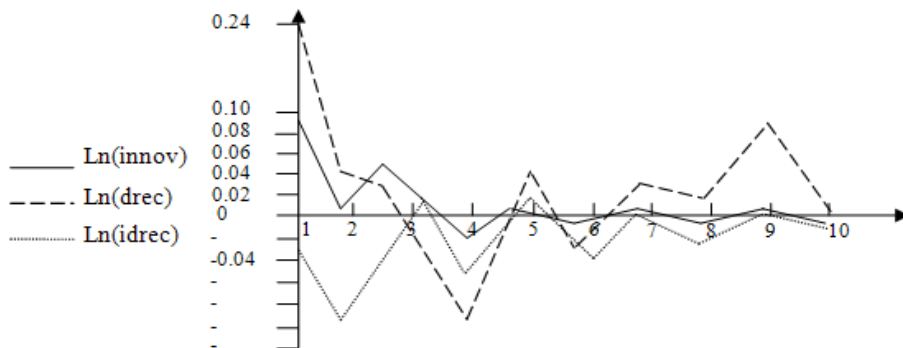


Fig. 4: Firm size impulse response tracks on technology innovation

Table 2: The average variance decomposition on technological innovation and firm size

Item	Ln (drec)	Ln (idrec)	Ln (innov)
Firm size variance decomposition average contribution to technology innovation (%)	32.290702	20.5095009	36.519862
Technology innovation Variance Decomposition average contribution to firm size (%)	4.4459876	3.8083335	7.3649921

response function strictly depends on error vector satisfying the white noise error vector. Then we use Generalized Impulse Response Function Method (GIRF) to examine the technology Innovation (INOV), Direct Technology Innovation (DREC), Indirect Technology Innovation (IDREC) and use the sales income to reflect impulse response between firms Sizes (SIZE). We obtained analysis result in Table 1; we set the impulse response period 10 considering the article's sample data capacity.

Impulse response track: The technology innovation impulses response on firm size based on generalized impulse response function means that change of firm size's dynamic influence track on technology innovation in a technology innovation-firm size interact economic system, so do firm size. We can draw conclusions from the imitation of impulse response result between technology innovation and firm size as follows: Firstly, firm size has different impact tract on different types of technology innovation (Fig. 3). Firm size expansion is greatly beneficial to direct technology innovation; however, supporting on direct technology innovation will be weaker by natural and physical bottleneck of technology paradigm and administration cost increases, because of organization complexity. Though firm size expansion is unfavorable of indirect

technology innovation, the inhibitory action on indirect technology innovation has been smaller and smaller, when direct technology innovation is in the weak and indirect technology innovation is active along with firm size expansion, but at this time the form of firm size expansion must have changed.

Secondly, different technology innovation types effect firm size in N model (Fig. 4), indicating technology innovation influences firm size in different ways. The result shows that instead firm size impacts on technology innovation, technology innovation impacts on firm size. The effect is more outstanding in long time. This may because along-track innovation following Technological Trajectories of technology innovation, especially direct innovation need a relative long time to establish and perfect under the mutual-construction of technology, market and organization and choose a firm size expansion method to accommodate technology.

Variance decomposition analysis: Then the author will adopt variance decomposition to decompose Mean Square Error into the devotion of every variable impulse in the system, in order to investigate Mean Square Error decomposition of any endogenous variable, variance decomposition get a result of various technology innovation and firm size show in Table 2.

As we can see in Table 2, firm size plays a more important role in technology innovation variance than various technology innovations. This is mainly because of our industrial enterprise expansion intention from view of technology innovation strategy is limited. The change of firm size follows merger, acquisition and alliance often get government intervention. As we all know, 'small-large alliance' and 'small-small alliance' among firms are not common, which aiming at achieving scope economy among small and medium enterprises, realizing industrial cluster in innovation area and sharing innovation source. All of those reflect that relation between firm size and technology innovation is decided by mutual-construction space of technology, organizations and market emerges in the whole system self-organization process, which has itself development law. So, we should not expand size for size factitiously.

DISCUSSION AND CONCLUSION

This study names the influence factors for the relation of technological innovation and firm size as technology, organization and market. All of these formed an interaction evolution space among their interactive mutual construction. Besides, the dynamic relation between technology innovation and firm size is the result of self-organization of the mutual construction system. The model of interaction evolution under the mutual construction shows that the change of technology, organization and market can lead to emergence of different kinds of technology innovation and firm size. It means that if regarding new technology produces the new organization and new market as the original state of the space motion; then technology innovation will develop from indirect technology innovation to direct technology innovation. At the same time, firm size will express different models on different stage. When direct technology innovation tends to be technology paradigm bottleneck, the diversification size expanding can anew active enterprise's indirect technology innovation and then turn into the next recycle of technology life period.

From the consequence of empirical analysis, the result of Generalized Impulse Function shows that interaction between technology innovation and firm size has obvious nonlinear relation characteristic. That supports our theory model and also point out any one of the two can be the reason of the other. The result of variance analysis shows that firm size has more direct obvious influence on technology innovation, while technology innovation's influence on firm size is weaker and evident hysteresis existence. This consequence also means that firm size is an important influential element on technology innovation, but we need to choose proper firm size, expanding method

with considering technology types and its life-period. For firm size, it is not the bigger the better, or whatever kinds of expanding methods are beneficial to technology innovation; what is more, technology innovation's retroaction on firm size has not been reflected sufficiently, the key factor is supplying more developing freedom to enterprise and taking enterprise as the main part of technology innovation authentically to express technology innovation strategy's influence on microcosmic enterprise development and decision expanding action.

ACKNOWLEDGMENT

This study is partially supported by Natural Science Foundation of China for youth project (71103027); Chinese Ministry of Education humanities and social science research projects for youth project (10YJC790154).

We also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

REFERENCES

- Abbate, J., 1999. *Inventing the Internet*. MIT Press, Cambridge, MA.
- Aghion, P., C. Harris, P. Howitt and J. Vickers, 2001. Competition, imitation and growth with step-by-step innovation. *Rev. Econ. Stud.*, 68(3): 1467-492.
- Birkinshaw, N.H. and Y. Stephen, 2005. Subsidiary entrepreneurship, internal and external competitive forces and subsidiary performance. *Int. Rev.*, 14(2): 227-248.
- Christensen, C.M., 1997. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Harvard Business School Press, Cambridge, MA.
- Charles, E., 1997. *Systems of Innovation: Technologies Institutions and Organizations*. Wellington House, London.
- Freeman, 1982. *The Economics of Industrial Innovation*. MIT Press, Cambridge, MA.
- Hulin, C.L. and M. Roznowski, 1985. *Organizational Technologies: Effects on Organizations' Characteristics and Individuals' Responses*. In: Cummings, L.L. and B.M. Staw (Eds.), *Research in Organizational Behavior*. JAI Press, Greenwich, CT.
- Les, G., 2001. *Organizations in multi-agent systems*. Proceeding of 10th European Workshop on Modeling Autonomous Agents in a Multi-Agent World Annecy, France.
- Mark, J. and F. Steven, 2001. Trajectories in the evolution of technology: A multi-level study of competition in formula 1 racing. *Organ. Stud.*, 22(6): 945-970.

- Nelsonand, W., 1982. An Evolutionary Theory of Economic Change. The Belknap Pressof Harvard University Press, Boston.
- Scherer, 1965. Firm size, market structure, opportunity and the output of patented inventious. *Am. Econ. Rev.*, 55(5): 1097-1126.
- Si, C., 2005. Enterprise Innovation Space and Technology Managemen. Qinghua University Press, Beijing.
- Tidd, J., J. Bessant and K. Pavitt, 2001. Chichester Managing Innovation: Integrating Technological, Market and Organizational Change, John Wiley, New York.
- Williams, C., 2009. Subsidiary-level determinants of global initiatives in multinational corporations. *J. Int. Manag.*, 15(1): 92-104.