CAPABILITY DEVELOPMENT IN CHINESE MANUFACTURING: A QUASI-BIOTIC PERSPECTIVE OF KNOWLEDGE EVOLUTION

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ABSTRACT

A quasi-biotic model of knowledge evolution has been applied to manufacturing technology capability development which includes product design and development and manufacturing process/workflow improvement. The concepts of "knowledge genes" and "knowledge body" are introduced to explain the evolution of technological capability. It is shown that knowledge development within the enterprise happens as a result of interactions between an enterprise's internal knowledge and that acquired from external sources catalysed by: (a) internal mechanisms, recources and incentives, and (b) actions and policies of external agencies. A matrix specifying factors contributing to knowledge development and types of manufacturing capabilities (product design, equipment development or use, and workflow) is developed to explain technological knowledge development. The case studies of Tianjin Pipe Corporation (TPCO) and Tianjin Tianduan Press Co. are presented to illustrate the application of the matrix.

Keywords: quasi-biotic model of knowledge; knowledge genes; technology capability development.

1 INTRODUCTION

With the progress of industrialization in China, technology plays a greater role as the key factor in domestic economic growth. However, the development of technological capabilities by Chinese manufacturing enterprises, essential for catching up with more advanced international competitors, is progressing at varying speeds. According to Nolan (2005), "China is the 'workshop for the world', rather than the 'workshop of the world'". There is also evidence that a substantial proportion of China's advanced industrial output and exports are either assembled high-tech products made from imported high-tech components or products of foreign companies based in China (Yuqing Xing, 2011). Consequently, the most important challenge that Chinese enterprises confront is how to enhance their technological capabilities and occupy the higher value added zones of production and supply chains.

According to Kim (1997), the technological development path for developing and emerging economies as latecomers is "purchasing—digesting—improving" technological knowhow. Zhao Xiaoqing (2001) identifies two approaches (which could be complemenatry) to technological capability development of enterprises: (a) internal, by which knowledge is accumulated through internal efforts including R&D, and (b) external, by which new knowledge is obtained from external sources through technology transfer, technology alliances and innovation networks. Keller (2004) focuses on the external approach and shows that technological development can be explained to a large extent by spillovers through international technology transfer. Krammer (2009) analyzes knowledge sources empirically using panel data of 16 transitional East European economies and shows that universities, public and private R&D institutes, foreign investment inflows and international trade are important external sources of knowledge which advance technological development. Therefore, technological capability development of an organization very much relies on its basis of knowledge accumulation or possession, knowledge inflows, and apropriate management of knowledge.

Our research on knowldege management suggests a "quasi-biotic model of knowledge evolution" as a new perspective on the development of technological capability, . According to the quasi bitotic model, the mass of all knowledge can be seen as a quasi-organism which evolves over time through the replication of "memes" (ideas or thoughts), with some parts of knowledge growing through linkages and because they are either valued intrinsically or for their usefulness, as is the case with technological knowledge, while others fail to replicate (Silby, 2000). Our focus is not the whole mass of knowledge but on the body of knowledge, especially technological knowledge, at the level of the enterprise and how it develops. We suggest four Knowledge Growth Factors (KGFs) which summarise the acquisition, interaction and enhancement of knowledge within an organisation.

(1) Knowledge endowments of the organisation.

Knowledge can be viewed as a quasi life-form growing organically. Therefore, much of "new" knowledge, some would claim all (see Silby, 2000), can be traced back to a pre-existing body of knowledge composed of memes or "knowledge genes" or compounds of knowledge genes which survive and are passed on from one generation to the next. For innovation within an enterprise, aside from acquiring knowledge from outside, there must be application and development of knowledge in its possession. An enterprise's knowledge endowment cannot be built in one day. In other words, innovation only happens over time if the enterprise has the human resources who possess certain kinds of knowledges and are adept at applying them and combining them with knowledge acquired from outside the enterprise to further develop the knowledge endowment. Therefore, an enterprise owes its innovation at least partly to its knowledge endowmenrt which consists of its "knowledge genes".

(2) Knowledge obtained from outside.

The organic and evolutionary nature of knowledge implies that learning and developing knowledge within an organisation is a process in which new internal knowledge is created from an existing base of knowledge.. For organisational knowledge development, without access to knowledge from outside, latecomers would have to repeat the process of developing existing knowledge and spend resources and time to acquire the knowledge other organisations have already mastered. Hence acquisition of knowledge from outside the organisation is a shortcut for latecomers to develop technological capability. The combination of knowledges at "intersections", for example when internal and external knowledge combine (Jinsheng He and Jinag Li, 2008), could be compared with the mutation of genes creating new forms of knowledge genes. In the SECI (Socialisation, Externalisation, Combination, Internalisation) model of innovation, Nonaka and Takeuchi (1995) argue that new knowledge ensues from interaction between different types of personnel in possession of different knowledges. Johansson (2004) states that the future of innovation lies only at the intersections. Therefore, in the manufacturing technology capability building process, knowledge transfer from outside is essential, but so is the knowledge inside the enterprise.

(3) Catalysts

Similar to enzymes required in biotic fermenting, knowledge development needs catalysts. In the development of manufacturing capability, mechanisms and motivations which enable and reward acquisition of knowledge and its application to enhance capabilities are such catalysts. Appropriate incentives for management and employees and enabling government policies are important in this respect.

(4) Objects and platforms

All human knowledge is the understanding of processes or objects. Knowledge growth relies on the processes or objects it deals with. A platform, such as a task or a project, provides a playground for doing things and thinking. A platform gathers resources and people which also creates knowledge and information clustering. Clustering of knowledge increases the chances of collision, debate, and integration of knowledge which induce recombination or extension of existing knowledge. It serves as a kind of knowledge fermenting "ba" or *milieu* (Jinsheng He, et al, 2005).

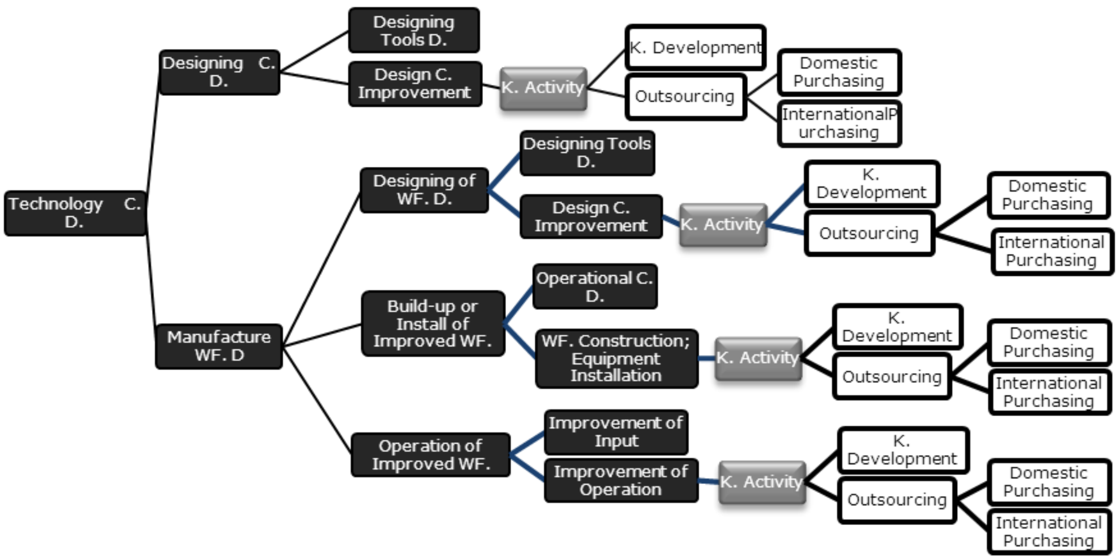
2 TECHNOLOGICAL CAPABILITY AND KNOWLEDGE BODY

In a living organism there is a relationship between DNA, and genes and the nature and functioning of the organism. We argue that in the knowledge arena there are knowledge genes which relate to the ”knowledge body” within an organisation in a similar way.

Biological genes are a set of encoding of information contained in the DNA which determines the biological function of an organism. Through the organism’s growing process genes “express” the information contained in them. In other words, the biological function under the control of a gene is only apparent after “gene expression” which uses the information contained in the gene to perform a function. We draw a parallel between biological gene expression and knowledge gene expression here. The function of knowledge genes is to guide human action. Therefore, knowledge genes have no function or strength before they are used in synthesis, analysis, decision making and actions. Knowledge is therefore expressed in addresseing issues and solving problems. In relation to the technological knowledge of an enterprise on which its technological capability is based, the functions or expressions of the relavant knowledge genes or of combinations of knowledge genes are represented in innovation activities. Therefore, the technological capability of an enterprise are dependent on the quantity and quality of its knowledge gene pool and the enterprise’s capability to apply it.

Figure 1 shows an example of the decomposition of the technological capacity of a manufacturing enterprise. The black boxes represent knowledge capabilities, the white boxes represent the sources of and approaches to gain knowledge genes, and the grey boxes represent knowledge activities that convert technological knowledge into technological capabilities.

Each step in the progress of manufacturing or technology capability development in Figure 1 can be traced to the development of product design or of the manufacturing process/workflow. Development of design capability is the result of knowledge activity undertaken by people (e.g. drawing, calculating, thinking, learning, brainstorming). Improvements of manufacturing process capabilities can be separated into design, installation, and operational capabilities. Except for the adaptation or development of equipment (hardware), all other capability development can be attributed to knowledge based activities. Hardware improvement can be traced to adaptation and design capabilities or manufacturing capability.



(D - DEVELOPMENT, WF - WORKFLOW, C – CAPABILITY, K - KNOWLEDGE)

Figure 1. The role of knowledge activity in Manufacturing Capability Development

In summary, the three main technological capabilities can be described as product design capability, equipment technology capability, and process building and improving capabilities. We refer to these as Technology Capability Expression (TCE). These capabilities are facilitated by the development of knowledge, i.e. by the functioning of Technology Growth Factors (TGFs).

3 KNOWLEDGE MECHANISM OF TECHNOLOGY CAPABILITY DEVELOPMENT

Based on the assumption that technology capability development is the result of improvements in the knowledge body, i.e the ability to assimilate and apply knowledge, an enterprise level knowledge mechanism of technology capability development can be proposed. In section 1 we have identified four knowledge growth factors that determine the development of knowledge: (a) knowledge endowment; (b) knowledge obtained from outside; (c) catalysts, and (d) objects and platforms. We identify three main types of manufacturing technological capabilities: (a) design capability; (b) equipment use, adaptation and developemnt capability, and (c) process/workflow capability. Other capabilities such as installation and commissioning of equipment can be also be included. In every technology capacity expression, we can differentiate the effects of each of the four knowledge growth factors through field research and analysis. Thus, we get a 3 X 4 matrix shown in Figure 2.

	Endowment Knowledge	External Knowledge	Catalyst Factors	Object and Platform
Workflow	Capability development on workflow			
Equipment	Capability development on equipment			
Product Design	Capability development on product design			

Figure 2. The technology capability development matrix

The row headings in Figure 2 represent the factors contributing to technological knowledge development of an enterprise. As stated in the previous section, knowledge development happens in the knowledge ba when the clustering, communication, and interactions of the enterprise's existing KGFs and KGFs acquired from external sources are catalysed by internal mechanisms and incentives and actions and policies of external agencies including the government. The column headings represent types of manufacturing capacity development, workflow, equipment and product design..

4 CASE ANALYSIS

In this section, we briefly illustrate the application of the framework to two state owned enterprises with a record of innovative efforts.

Tianjin Pipe Corporation (TPCO)

TPCO is a state-owned firm with 40 per cent share of the domestic seamless steel pipe market. It is also one of the world's biggest manufacturers of seamless steel pipes for the oil and gas industry. About 5 per cent of its annual revenue is invested in R&D and the company has over 300 scientists and technicians engaged in R&D. Since 2007, TPCO has registered approximately 50 patents annually.

In 2003, TPCO put a triple roller mill for pipes into production, the first of its kind in the world. It was originally commissioned from and designed by a German manufacturer but because of some technical flaws it could not be put into production. TPCO made a number of changes in collaboration with the supplier and finally made the equipment operational. In this case, the path of TPCO's technological capability development can be expressed as in Figure 3. The importof new equipment was accompanied by capacity expansion, increased R&D, widening of the product range and internal restructuring of the business leading to a tripling of output and sales between 1997 and 2005 and almost doubling of output and sales between 2005 and 2010. In the process of re-engineering of TPCO, a global manufacturing system has been established.

	Knowledge Endowment	External Knowledge	Catalyst Factors	Object and Platform
Workflow	Workflow maturing and then expanding: 1. Enlarging scale. 2. Increasing product range. 3. International operations: expansion of exports and set up production abroad.			
	Firm started during reform period. Accumulated national expertise and internal R&D to form initial knowledge base.	Management concepts and imported equipment and expertise).	Reform of state-owned enterprises: Debt swapped for shareholding. Market system.	Objective of establishing strong position in domestic and overseas markets.
Equipment	Collaborative development of triple roller mill. Exclusive right to use the equipment for 5 years. Gained expertise in using and adapting equipment.			
	Had the capacity to commission advanced equipment and make it operational. Collected best domestic specialist talents.	Design of triple roller mill from German maker. Collaboration to make it operational.	Win-win collaboration for mutual benefit.	Triple roller mill installed to gain international lead. Cooperative R&D on key technologies.
Product Design	1. Annual output of 3.5 million ton seamless pipe and 1.5 million ton petroleum casing tube. 2. 12 laboratories for R&D developing more advanced products.			
	Basic product development capabilities at the beginning. Expansion of R&D.	Cooperation with domestic research institutes and Universities.	Government S & T system reform. Incentives for knowledge based production.	Domestic and foreign demand for from oil and gas industries and elsewhere.

Figure 3. The technology capability development matrix for TPCO

	Knowledge Endowment	External Knowledge	Catalyst Factors	Object and Platform
Workflow	Radical BPR (business process reengineering): 1. Internal concentration on marketing, design, key components and assembly. 2. Outsourcing other components. 3. Related downsizing to reduce costs. 4. More knowledge-based employees in R&D department.			
	Accumulated from experience of operating imported technology supplemented by internal R&D.	Following international trend of focusing on core competence. Domestic Reform experience	Operating on commercial principles. In state ownership but supported by progressive holding company.	Objectives of maintaining lead in China and becoming internationally competitive. Trial and error permitted under stable regime.
Equipment	1. Importing core equipment. 2. Gantry crane being made.			
	Operation, design and manufacture of basic equipment.	Purchasing most advanced equipment (e.g. horizontal milling machine from PAMA). Transfer of skills from equipment supplier.	Project loan from World Bank in 1990s for purchasing core equipment. Continuing reforms.	Equipment consistent with restructured enterprise after BPR. Focus on equipment for machining of key parts.
Product Design	Seven main series of machines with hundreds of variations hydraulic press machine tools with different pressing capacities and precision levels.			
	Basic product design capability. Enlarging of R&D department.	Part of Tianduan Design Academy which includes national institutes and technology centres.	Government S&T system reform..Incentives for R&D employees.	Market opportunities expanded: Automobiles, shipbuilding, aviation. Designing customer specific products.

Figure 4. The technology capability development matrix for Tianduan

Tianjin Tianduan Press Co.

Tianduan was established in 1956 under the planned economy and produced the first hydraulic presses in China. Now the enterprise is the largest manufacturer of hydraulic press machine tools in China. Its products have been exported to over 30 countries and output and profits have improved dramatically along with technology capability development after the implementation of policy reforms and transformation to market economy. Its improvement of technological capability has been outlined in Figure 4. The appraisal identifies the major knowledge sources and mechanisms and facilitators of change and can guide the formation and implementation of strategies and policies. Following business process engineering, Tianduan focuses on product design and development and manufacturing core components, outsourcing standard components.

5 SUMMARY AND CONCLUSIONS

Manufacturing capability development is in essence technological knowledge development and its application. We have identified four elements required for learning and innovation by enterprises from the knowledge development perspective: (a) knowledge endowment; (b) knowledge acquisition; (c) platforms for knowledges to interact to pursue objectives, and (d) catalysts which enable and stimulate knowledge enhancement. The case studies show that the four elements are relevant for workflow, equipment and product improvement. The proposed framework illustrates a quasi-biotic mechanism of knowledge development in which knowledge genes from (a) and (b) mutate into new knowledge in a knowledge fermenting “ba” (c) aided or stimulated by catalysts (d). The approach can be applied to evaluate the manufacturing capabilities of enterprises and to formulate their innovation strategies.

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