

R&D and Software Firms' Productivity and Efficiency: Empirical Evidence of Global Top R&D Spending Firms

Dan Tian

*School of Management Science and Engineering,
Dongbei University of Finance & Economics, Dalian 116025, China*

tiantan@dufe.edu.cn

Abstract

The main objective of this study is to investigate the impact of corporate research and development (R&D) activities on firm performance. To this end, the stochastic frontier technique is used on a unique balanced longitudinal dataset comparing top global software enterprises over the period 2005-2010. The software companies is divided into system software companies, application software companies and service software companies according to the types of product or service of software companies. In this framework, this study analyzes the effect of R&D, capital and employment on sales, and quantifies technical inefficiency of individual firms. The results of this study suggest that there are two ways in which R&D can influence the system software enterprise, one is to promote the frontier production function boundary forward, namely, to complete technological progress to improve the productivity of enterprise; another one is to improve the technical efficiency of enterprise and reduce waste. With respect to the application software enterprises, R&D can only improve productivity through technological progress; the effect of R&D on software service companies is not significant.

Keywords: *Software industry; R&D efficiency; Productivity; Stochastic frontier analysis*

1. Introduction

The modern business context is transitioning to knowledge-based economies, increasing the weight of knowledge-intensive sectors as a way to improve productivity and efficiency. Software industry is a typical knowledge-intensive business service. Software development is a knowledge-intensive process, where knowledge is created and shared, when different aspects of a software development process (concepts, products, tools, process, people, *etc.*) interact with each other. R&D investment is intended to generate knowledge to fuel the growth of firms and the economic system as a whole. Therefore, R&D plays an important role to software firms' productivity and efficiency.

With this in mind, the goal of our work is to enhance the analysis of variables influencing software firms' productivity and efficiency: thus we focus our investigation on the study of the effect of R&D, capital and employment on sales.

Policy makers and business leaders generally assume that corporate R&D activities have a positive impact on the economic performance of an enterprise. However, recent reports by Booz-Allen-Hamilton conclude the contrary [1]. This report offers support to the view that the share of spending devoted to R&D has no relationship to firm growth, profits, and value. Furthermore, the relationship between R&D investment and a firm's performance varies

depending on the industry of the analysis. There are few results from software industry point of view to analyze correlation of R&D and firm productivity.

The main object of this study is to analyze the impact of corporate R&D activities on firm performance. To that end, we analyze a sample of 39 software enterprises, covering the period from 2005 to 2010. The database comes from industrial R&D Investment Scoreboard (from Eurostat).

The present article is organized as follows: following this introduction the references of software industry and the influence of R&D activities are presented in Section 2; data, model and empirical results are presented in Section 3, 4 and 5; in Section 6 we provide conclusions and policy implications.

2. Literature

The literature of research and development (R&D) generally assumes that R&D has a positive impact on corporate performance, for example, the seminal article by Griliches [2] and more recent contributions by Klette and Kortum [3], Janz *et al.* [4], Rogers [5], Löf and Heshmati [6], and Heshmati and Kim [7]. All these authors point out that there are strong positive correlations between R&D (knowledge creation) and firm growth. The software industry is the quintessence of the knowledge-intensive industry. It is characterized by a high rate of product and process innovations, high knowledge intensity, rapidly shrinking product and technology life cycles, global market [8]. Romijn and Albaladejo found that in small hi-tech companies, specialised knowledge and experience in science and technology should be in place [9].

However, software development highly depends on skilled and creative employees rather than technology. Different from other industries, technology-orientation has a negative impact on the software industry [10]. Nowak and Grantham study California software industry, the California case illustrates clearly that human capital – attracting and retaining the right talent is the critical resources for software industry [11]. Ethiraj *et al.* using a large sample of detailed project-level data from a leading firm in the global software services industry, find that two broad classes capabilities are significant, that are client-specific capabilities and project management capabilities [12]. Akman and Yilmaz found that customer-orientation is one of the important factors that significantly affects the innovation capability, and they also pointed out that inter-functional co-ordination is another factor that has a significant effect on innovative capability [10]. Software development team creativity is positive related to a creative climate, *e.g.*, challenging work, freedom and group support [13]. In the software industry, analysis and design has become the crucial phase in software development. A good software design can be reused in other projects, will shorten the development period and, ultimately, the costs as well [14].

For manufacturing industry, R&D has improved the productivity and reliability. For software industry, does R&D has a positive relation to firms' performance? That is an unanswered question. Furthermore, the software industry does not require more capital or investment to begin, so it is an important opportunity for developing countries that have limited economic resources [10]. Therefore, our paper analyzes the effects of R&D and capital to software corporation performance, and selects top R&D spending firms of global 1000 during the period 2005-2010 as research samples.

3. Methodology

There are two methods applied to measure productivity efficiency, which are parametric and non-parametric methods. Both have strengths and limitations. Stochastic Frontier

Analysis (SFA) is parametric one, which is constructed in 1977. SFA method makes it possible to test hypotheses using econometrics, take account of Composed error terms including statistical random error term and one-side inefficiency component, provide parameter estimates of production factors, elasticities, etc., for possible further interpretation. But it imposes a somewhat ad hoc assumption on the functional form on the frontier to be estimated, together with assumptions on the distribution of the composed error terms. Data Envelopment Analysis (DEA) is non-parametric method. It does not require such assumptions, and is comparably easy to calculate for avoiding analysis of several variables' quantitative relation. However, it does not consider time series and relating technical inefficiencies to exploratory variables.

Recently, scholars use panel data to estimate stochastic frontier model. This method is widely applied to analysis of productive efficiency. Productive efficiency means the degree of success producers achieve in allocating the inputs at their disposal and the outputs they produce, in an effort to meet some objective. Panel data contain observations of multiple phenomena obtained over multiple time periods for the same productive units, and provide more accurate and reliable information to estimate SFA model.

Our goal is to analyze whether R&D activities and physical capital affect productivity and technical efficiency for software industry. If yes, we farther analyze to what extent, and how these factors affect. Therefore, we adopt SFA model to study productivity and technical efficiency of software industry.

4. Data

4.1. Sources

The empirical analysis is based on the panel data consisting of 39 top software enterprises over the 6-year period 2005-2010. This unique dataset was collected from top R&D scoreboard data of European Commission's Joint Research Centre and Directorate General Research. This R&D scoreboard provides fiscal accounts of top global companies and top European ones. The data is abstracted from publicly available audited accounts, is timely and reliable, and provides evidence for R&D comparisons of different regions, industries and companies. We download data from web page of Joint Research Centre, clear up data manually, and obtain figures of sales, R&D investments, capital expenditures and employees.

In order to get representative sample and improve sample research validity, we select companies' consecutively entering scoreboard from 2006 to 2011, and get 42 companies totally. The companies publish annual report including last year's accounting data at the beginning of this year, so the sample range is actually from 2005 to 2010. After obtaining original data, we computed knowledge and physical capital stocks using the perpetual inventory method. Because the data through calculation of R&D capital stock of the Unisys and Tibco Software in 42 software enterprises is negative, we eliminated them. In addition, because the number of employees Nice Systems in 2008-2010 is absent, we also removed it. Finally there are 39 software enterprises as the research sample.

4.2. The classification of software enterprises

The software industry is the production or manufacture of software products or services; however, the classification for the software industry has not yet formed a unified standard. According to the North American Industry Classification System, the software industry includes System Software Publishing, Application Publishing and Other Services. The FTSE and Dow Company jointly established the Industry Classification Benchmark (ICB) which

divide the Software & Computer Services (Sectors) into "Computer Services", "Internet" and "Software" Subsectors. By comparison, the United States of America classification method is more in line with the industry and the academic circles habits, therefore, we use the classification method of the United States of America, and the software industry is divided into system software companies, application software companies and services software companies.

The research of data source in Scoreboard, it adopts the classification method of FTSE and Dow Jones; we choose to modify the data according to the classification method of the United States of America. We choose the "Computer Services" and "Software" industry enterprises in the Scoreboard disclosed in the top 1000 global research enterprise as samples. On this basis, according to the American industry classification code NAICS, we attributed 5 companies to service software enterprise which belong to Computer Services industry; according to 2012 Software 500 Companies issued by Software Magazine Online, we divided the enterprises in Software Industry into 8 system software enterprises and 26 application software enterprises.

4.3. The definition of variables

This study selects the tangible capital stock per capita as a dependent variable. Capital expenditure is refers to the costs enterprises purchase or upgrade of fixed assets (such as equipment, property, plant, and outflow), it reflects the impact of fixed assets on corporate performance; in addition, the per capita stock of physical capital can eliminate the effect of enterprise scale. Hu and Wang argue that the capital stock (i.e. tangible capital) as a measure of capital investment index is suitable [15]. Therefore, the perpetual inventory method to calculate the stock of tangible capital expenditure is needed.

$$C_{t0} = \frac{I_{t0}}{g_j + \varphi} \quad (1)$$

I for the capital expenditure, the average g growth for the rate of capital expenditure from 2005 to 2010, φ for Depreciation rate, usually taken as 6%; j=1, 2,.....39, ,T0=2005.

$$C_t = C_{t-1}(1 - \varphi) + I_t \text{ For } t=2005, \dots, 2010 \quad (2)$$

This study chooses the capital stock per capita R&D as the dependent variable. R&D capital shows the influence of innovation performance on enterprise competitiveness, especially in high technology industry [16]. R&D capital stock is obtained through the perpetual inventory method for calculating annual R&D funds, R&D fund is refers to the R & D investment for enterprise itself, without R & D outsourcing funds, government grants, and cooperative R & D funds etc.

$$K_{t0} = \frac{R \& D_{t0}}{g_j + \delta} \quad (3)$$

R&D for the enterprise R & D funds, the average g growth for the rate of R&D funds from 2005 to 2010, φ for Depreciation rate for R&D , usually taken as 15%; j=1, 2,.....39, ,T0=2005.

$$K_t = K_{t-1}(1 - \delta) + R \& D_t \text{ for } t=2005, \dots, 2010 \quad (4)$$

This study chooses human capital, namely enterprise employees as the dependent variable. The number of employees reflects the scale of enterprises. According to Schumpeter's Hypotheses, the larger enterprise scale is, the stronger the corporate R & D strength and ability to resist market risk is [17]. Software industry is typical knowledge intensive service enterprises; in the process of software product development, system designers, programmers is the main input, rather than raw materials, plant and equipment required for manufacturing. Therefore, we select the number of employees as the main dependent variable; on one hand, it can be control variables to reflect the enterprise scale, on the other hand, combined with the actual production characteristics of software enterprises.

5. Model

We constructed the model using the stochastic frontier approach; the frontier production function defines the maximum output in the given input factor, output as the enterprise sales revenue:

$$Y_{it}^* = f(K_{it}, C_{it}, E_{it}; \beta) \exp\{v_{it}\}, i = 1 \dots 39; t = 2005, \dots, 2010 \quad (5)$$

Y_{it}^* is the maximum output for enterprise 'i' in 't', $f(\cdot)$ is the production function, inputs include the stock of knowledge capital (K_{it}), capital stock (C_{it}) and employee (E_{it}), β is the estimated parameter, v_{it} is the random error term.

$$Y_{it} = Y_{it}^* \exp\{-\mu_{it}\} \quad (6)$$

$$\text{Or, } Y_{it} = f(K_{it}, C_{it}, E_{it}; \beta) \exp(v_{it}) \exp(-\mu_{it}), i = 1, \dots, 39; t = 2005, \dots, 2010 \quad (7)$$

Equation (6) represents the maximum output enterprise can reach in a given investment, but in fact, the enterprises, due to various factors, cannot achieve the maximum output; therefore, Y_{it} represents the actual output of enterprises. This study selects sales per capita to represent the output, R&D capital stock per capita, tangible capital stock per capita and human capital as inputs, assumes that the production function is Cobb Douglas log linear equations, logarithmic equation as follow:

$$\ln(S_{it} / E_{it}) = \beta_0 + \beta_1 \ln(K_{it} / E_{it}) + \beta_2 \ln(C_{it} / E_{it}) + \beta_3 \ln E_{it} + v_{it} - \mu_{it} \quad (8)$$

$$\text{Effective technology } TE_{it} = \exp(-\mu_{it}) \quad (9)$$

$$\text{Or } TE_{it} = \frac{Y_{it}}{f(K_{it}, C_{it}, E_{it}; \beta) \exp\{v_{it}\}} \quad (10)$$

For $TE_{it} \leq 1$, $\mu_{it} \geq 0$, and μ_{it} follows $N^+(0, \sigma_{\mu_{it}}^2)$.

$$\text{In which } \sigma_{it}^2 = \delta_0 + \sum_{j=1}^M \beta_j z_{j,it} \quad (11)$$

6. Analysis of the Results

We first analyze the overall situation of software industry, assume that the type of enterprise has influences on both the productivity and the technical efficiency, and analyze

the system software enterprise, application software enterprise and service enterprise. Effects of R&D investment and human capital on system software enterprises is the largest, followed by the application software enterprise, and are not significant on software service enterprise; influence of tangible capital on system software enterprises is greatest, followed by software service enterprises, and is not significant on the application software enterprises. The influences of R&D density on technical efficiency of system software enterprise are significantly positive, those of application software enterprise are significantly negative, and those of software service enterprises are not significant. Year is on behalf of the influences of other factors on the technical efficiency, the time of sample data span from 2005 to 2010 years, therefore, we take the Year to represent the impact of the economic crisis on software industry.

Table 1. The estimation parameters of the stochastic frontier model

The production function	All enterprises		System software		Application software		Software service	
	Coefficient	t-value	Coefficient	t-value	Coefficient	t-value	Coefficient	t-value
ln(K/E)	9.7715***	21.1611	4.5301***	6.1760	10.1046***	17.7887	17.9038***	23.9147
ln(C/E)	0.1770***	4.9158	0.3049***	3.4766	0.1467***	3.1334	-0.4813***	-4.0030
lnE	0.0100	0.3671	0.2174***	3.0457	-0.0024	-0.1135	0.0167*	1.3438
lnE	0.0527***	2.9462	0.1697***	7.3937	0.0400*	1.4836	-0.0164***	-4.4911
Technical inefficiency function								
Type(1)	0.1107	0.9941	-0.4060***	-2.8074	-0.7262***	-2.5518	0.2936***	3.6354
Type(2)	-0.0934	-1.0756						
R&D intensity	-0.1815***	-3.2237						
CAP intensity	0.9094***	2.4732	-5.8626***	5.1539	2.1201***	3.0523	-0.9351	-0.7167
Time	0.0119	0.0107	-0.0254 [‡]	-3.0256	0.0092	0.0098	-0.1337	-0.0200
The number of enterprises	0.0148	1.0578	0.0352	-1.4503	0.0586 [‡]	2.1049	0.0627**	2.1288
The average efficiency	39		8		26		5	
	0.7674		1		0.9534		0.7246	

6.1. Model for all enterprises software industry

First, we take the stochastic frontier approach to analyze the effect of R&D capital, physical capital and human capital on productivity of software industry. Effect of intellectual capital on software industry productivity is positive and significant, with coefficient of 0.1770, which means that the productivity in the software industry has increased by 0.1770% for every 1% increase in R&D capital stock; the effect of human capital on software industry productivity is positive and significant, with coefficient of 0.0527; however, the effect of human capital on the software industry is less than R&D capital; the effect of physical capital on the productivity of software industry is not significant. The software industry is a typical knowledge intensive service industry, development of software products or services mainly depends on the R&D input, software engineers and computer hardware; with the decreasing hardware cost, influence of physical capital on productivity is very little.

In the technical inefficiency function, we mainly analyze the influences of type of enterprise, R&D density, capital density and time on technological efficiency. Type (1) is a dummy variable, the value of 1 for type of software service enterprises, whereas the value of 0 for type of others; type (2) is also the dummy variable, the value of 1 for type of system software service enterprises, whereas the value of 0 for type of others. The effects of type (1)

on technical efficiency are not statistically significant, the coefficient of type (2) is negative; therefore it has positive effect on technical efficiency, which means that system software enterprises have a higher technical efficiency. Coefficient of R&D density is positive; therefore it has negative effect on the technical efficiency, which means that the higher the R&D density is, the lower the technical efficiency is. The output of R&D is the new technology. To realize the technology commercial success, enterprises also need a suitable business model, for example, Xerox Palo Alto Research Center invented the technology of graphical interface, but put it away unheeded, then it was widely used by the Apple Corp and Microsoft in the market, and Microsoft even become the industry leader. In addition, capital density had no significant effect on technical efficiency of enterprise, which is consistent with the result of production function. Year represents other factors on the technical efficiency of the software industry, and year has no significant effect on the technical efficiency. Type (2) has a significant effect on technical efficiency; therefore, we divided the whole software industry into system software, application software and software service enterprise, to further analyze the impact of knowledge capital, physical capital and human capital on segmentation of industry.

6.2. Software system enterprises

The effect of R&D capital, physical capital and human capital on the productivity of software system enterprise productivity is significantly positive, with coefficients of 0.3049, 0.2174 and 0.1697. Software system enterprise products are mainly involved in operating system software, network software, database management software, development tools and programming language software etc... The main functions of the system software products lies in the control and coordination of external computer equipment, and the support of application software operation; technology and capital barriers are high with long development cycle and high risk of research, in which often require long-term, huge R & D funding support; therefore, effect of R&D capital on the productivity is highest.

The effect of R&D density and physical capital density on technical efficiency of the system software enterprise is significantly positive. System software development difficulty is huge, in the industry with high barriers to entry, competition is not very intense; system software industry has long been monopolized by a few enterprises with few foreign enterprises to enter, the monopoly enterprise has prominent technical ability, great overall strength, and rich development experience, these skills and abilities is difficult to imitate by other enterprises; therefore, the more enterprise invest in research and development, the higher the technical efficiency of it is. The effect of year variables on the efficiency of system software enterprises is not statistically significant, the economic crisis of 2008 has made a smaller impact on the software system enterprise, this is because they have devote huge investment for equipment and to improve the quality of personnel, then they has grasp the core technique in the supply chain, in which downstream enterprises must use their technology even in the economic crisis.

6.3. Application software enterprise

The effect of R&D capital and human capital on the productivity of software enterprises is significantly positive, with R&D capital in greater influence. The coefficient of R&D capital in the software enterprise model is 0.3049, and in the application software enterprise model is 0.1467. Unlike system software enterprises which are involved in technique problems, application software enterprise products are mainly involved in commercial and domestic software, cross industry applications, vertical market application software and utility

software. Compared with the system software, technology of application software is relatively low; application software products has paid more attention to develop the needs of the user than the system software product, but they also must master the core technology, in order to attract downstream software enterprises to use the products, and then expand the market scale. The effect of human capital on productivity of application software enterprises is significantly positive. Application software enterprises usually need to provide service for the user to increase the added value of the products, which need the support of human capital. Effect of capital on the application software productivity is not statistically significant, indicating that the application software enterprises have low requirement on the equipment and capital; therefore, foreign competitors are easier to enter the field, hence more intense competition in the market.

The effect of R&D density on technical efficiency of application software enterprises is negative. Application software is responsible for the implementation of specific business functions in the computer system, such as enterprise resource planning (ERP), customer relationship management software (CRM), supply chain management (SCM) software, financial management software, etc... Application software product varies, and is easier to develop than the system software; the enterprise should not only master the software development technology, but also need to have the knowledge and expertise, and industry knowledge localization. Local knowledge, the knowledge background of country or region where the enterprise is related with; industry knowledge means the knowledge of industry supply chain structure, production process, and the user; specialized knowledge is refers to the complete solution of products and services for the user. As for local knowledge ,professional knowledge, and specialized knowledge, once they are applied to product development, it is easy for other enterprises to imitate, the pursuer can play the catch-up advantage to realize technology which means enterprises which have much R & D investment failed to benefit from advanced technology.

6.4. Software service enterprises

The effect of R&D capital and human capital on software service enterprise productivity is significantly negative, physical capital has a significant positive impact on productivity. Software service enterprise used the products of system software enterprises and application software enterprise, customized according to the actual business environment of enterprise users, and provided total solutions, they are the used of technology rather than developers, therefore, the R&D input has little effect on the productivity of enterprise. The core competence of software service companies is the ability of project management, and obtaining this ability need enterprises to invest long-term, sustained for infrastructure and system of investment, so the physical capital has a significant positive effect on productivity. The effect of human capital on productivity of software service enterprises is negative, which contradicts our common sense; generally, we believe service enterprises is labor intensive, more staff should promote the productivity of enterprise. In fact, the leading performance software service enterprises usually develop user innovation toolbox, toolbox includes general function module, and special function module are developed by the enterprise, thus reduce the use of human capital and service enterprises, and improve the productivity.

The effect of tangible capital density and capital density on the technical efficiency is not significant. The year coefficient has a significant negative impact on technical efficiency. The year coefficient is representative of other factors that influence the technical efficiency, out panel data spans the years from 2005-2010; the 2008 economic crisis, bring negative impact on the software industry, which is the most important factor to reduce the technical efficiency.

6.5. Analysis of software industry technical efficiency

System software enterprises own the highest efficiency of about 1.000 in each year, system software products have high profit margins, namely, once developed, their replication cost were low; software system enterprise realized their profit mainly by large-scale application system software, which makes the technical efficiency of system software enterprise prominent; technical efficiency of application software enterprises is ranged in 0.9205-0.9782, overall showed a downward trend year by year; the minimum technical efficiency belongs to that of software service enterprises, in the 0.5932-0.8963 range, and the efficiency decreased in 2008, then show an upward trend after 2009 with the overall shape of U. The overall technical efficiency of software industry is between 0.7380 and 0.7988, and showed a declining trend.

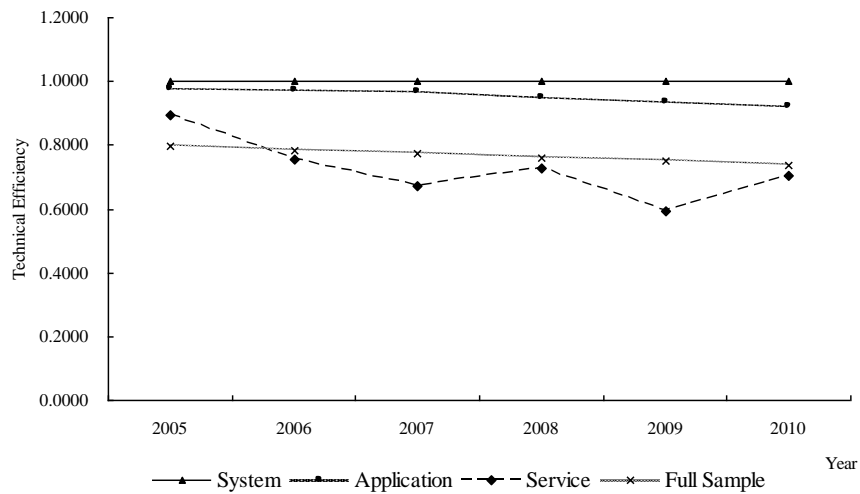


Figure 1. Comparison of technical efficiency of software enterprises

R&D density has a significant positive effect on technical efficiency of system software enterprise, a significant negative effect on the application software enterprise, and no significant influence on software service enterprise; capital density has a significant positive effect on technical efficiency of system software enterprise, has no significant effect on application software and software service enterprise; the year coefficient has a significant positive only to the efficiency of software service enterprise. The results show that the technical efficiency of the software industry show the overall downward trend; improving the capital density and the R&D density plays a significant role in improving the efficiency of system software enterprises, has no significant effect on application software and software services company, or even have negative effect.

7. Conclusion and Policy Recommendation

We use the panel data of software enterprises in the top 1000 enterprises research for R&D in 2005-2010, and study the effect of physical capital, R&D capital and human capital on software industry productivity and technical efficiency. According to the international software industry classification standard, we divide the software industry into system software enterprises, application software enterprises and software service enterprises. We

adopt the stochastic frontier model, respectively in the whole software industry and three type enterprises in software industry, the empirical results are as follows:

(1) With respect to software industry productivity, the effect of R&D capital is most significant on the productivity of system software enterprise, then comes the application software enterprises, and is not significant on software service enterprises; the effect of tangible capital is most significant on the productivity of system software enterprise, then comes the software service enterprises, and is not significant on application software enterprises; human capital has positive influence on the system software enterprises and application software enterprises, and has a negative impact on software services enterprises.

(2) With respect to the technical efficiency in software industry, R&D density can increase technical efficiency of system software enterprise, can reduce the technical efficiency of application software company, and had no significant effect on technical efficiency of software service enterprises; tangible capital density can improve the efficiency of system software enterprises, and has no obvious effect on application software enterprise and software services enterprises.

(3) There are two ways in which R&D can influence the system software enterprise, one is to promote the frontier production function boundary forward, namely, to complete technological progress to improve the productivity of enterprise; another one is to improve the technical efficiency of enterprise and reduce waste. With respect to the application software enterprises, R&D can only improve productivity through technological progress; the effect of R&D on software service companies is not significant.

R&D has different effects on different part of the software industry, and the effect of executive in R&D of system software enterprise is obvious; the enterprises should pay attention to the innovation of the commercial mode, and find the right opportunity for the industrialization of new technology; for application software enterprises, they should avoid the waste, and improve the efficiency of R&D activities; for software services enterprises, they should increase R&D intensity, and complete technological progress to promote productivity and technical efficiency, rather than investing physical capital to improve the performance of enterprises.

The software industry is the strategic industry relating to national security. However, the software enterprises of the United States and Europe are in a monopoly position in the system software, application software and other fields in the long time; the software industry of India is located in the international market, developing the software outsourcing services vigorously, by virtue of its labor advantage with low cost and high quality. In contrast, Chinese enterprises are less developed in software product technology and R&D investment, if we want to achieve rapid breakthrough in the software industry, we must adopt different strategies according to the development characteristics of different types of software enterprises. Among them, the product technology's form of system software enterprise is complex, and product development is difficult in itself. Due to the reason that it is not with a high level of technical ability of the background, the enterprise can use open source software in the development process, or build industry alliance to improve the efficiency of innovation; enterprise application software development model should pay attention to the local market demand, introduce advanced technology of the upstream enterprise, and match demand to technology effective ; service software enterprise development model should emphasize the clear positioning of enterprises in the industry value chain, focus on the integration development system, innovate the product launch platform to improve the quality of service, attract attention to customer needs, and provide customized solutions for client software.

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Author



Dan Tian

She received her PhD in Management (2008) from Dalian University of Technology. Now she is an assistant professor of management science at school of Management Science and Engineering, Dongbei University of Finance and Economics. Her current research interests include technology management of software industry and risk management.

