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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 8 (4): 589-594, 2009
ISSN 1812-5638

Knowledge Transfer Optimization Simulation for Innovation Networks

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Abstract: Based on the characteristics of knowledge transfer in innovation networks, an optimization model of the discount expectation of profits is presented, which can determine the optimal time of knowledge transfer. Important factors, such as knowledge absorption capacity, update rate of knowledge in the network, discount rate, the time of knowledge transfer, market share, product life cycle, etc. are taken into account in the model. A large number of simulated experiments are implemented to test the efficiency of the optimization model. Simulation experimental results show that the calculated results are in accordance with the actual economic situation. The optimization model can provide useful decision support in knowledge transfer time for enterprises.

Key words: Optimization, simulation, innovation networks, knowledge transfer, discount profit

INTRODUCTION

Innovation network is a social context of enterprises and research institutes which are linked to one another to share resources and knowledge to gain critical competencies that contribute to their competitiveness in the marketplace. In this special network, the nodes are enterprises or research institutes, the edges are relations among enterprises or research institutes.

Due to the importance of innovation networks in modern society, various researchers have carried out a lot of researches on the formation and evolution of innovation networks (Debresson and Amesse, 1991; Chang and Harrington, 2007), the factors which influence the knowledge transfer in innovation networks (Cummings and Teng, 2003; Bae and Koo, 2008; Coccia, 2008; Tang *et al*., 2008) and how to enhance the efficiency of knowledge transfer (Reagans and McEvily, 2003; Kotabe *et al*., 2003; Hoffmann, 2008). Research has also showed that knowledge transfer plays a key role in innovation networks (Varga, 2000; Hovorka and Larsen, 2005; Knudsen, 2007; Mihelcic *et al*., 2007). Useful techniques to enhance the efficiency of knowledge transfer have also been developed by Tang *et al*. (2004), Sabherwal and Sabherwal (2005) and Matsuno *et al*. (2007).

However, there are few researches on how to determine the optimal time of knowledge transfer to maximize the profit of an enterprise. Taking into account of several important factors such as knowledge absorption capacity, update rate of knowledge in the network, discount rate, market share and life cycle of a product, we will present an optimization model to determine the optimal time of knowledge transfer. A large number of simulated experiments will be carried out to prove the model is feasible as a basis of decision support of time optimization of knowledge transfer for enterprises.

BACKGROUND TO TIME OPTIMIZATION IN KNOWLEDGE TRANSFER

Knowledge transfer can be drawn from the expression: Let G = G (V, E) be an innovation network, where, $V = \{V_i\}$ is the set of nodes (enterprises or research institutes) in the network, $E = \{e_{i,j}\}$ is the set of edges (knowledge transfer) between nodes, $1 \leq i, \leq j \leq |V|$ and $|V|$ is the number of nodes in V.

Knowledge in innovation networks can be divided into two types, common knowledge and private knowledge (Khanna *et al*., 1998). It is assumed that common knowledge is the knowledge shared freely by all the nodes in the network. The ability to utilize the common knowledge only depends on the absorptive capacity of a node. On the other hand, private knowledge is the knowledge that can bring innovative profits and expand market share for related nodes. If a node wants to get private knowledge from another node, it should pay knowledge transfer cost. We only consider links of nodes based on private knowledge and we shall limit ourselves to the definition 1 below:

Definition 1: Let V_i and V_j be two nodes in G (V, E), if $e_{i,j} = 1$ then there exists knowledge transfer between V_i and V_j, if $e_{i,j} = 0$ then there is no knowledge transfer between V_i and V_j.

To make the optimization model simpler and practical, we formulate the following hypothesis.

Hypothesis 1: All the nodes in G (V, E) have only one product, whose marginal cost (Mansfield and Gary, 2003)

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in the starting period is MC. The marginal cost will decline at a rate of α ($0<\alpha<1$).

Hypothesis 2: The total market volume of the product is Q. The market share of each node in the starting period is ϕ. The total market volume increase at a rate of θ_1($0<\theta_1<1$) in the first L_1 periods and will decrease at a rate of θ ($0<\theta<1$) in other periods.

Hypothesis 3: All nodes in G (V, E) share only one private knowledge whose transfer cost in the starting period is k. If the knowledge is transferred to a node, the market share of this node will increase at a rate of ρ ($0<\theta_1<\rho<1$) in the first L periods immediately after knowledge transfer.

Hypothesis 4: The update rate of the knowledge in G (V, E) is β.

Hypothesis 5: The life cycle of the product in G (V, E) is N, which should be reset after knowledge update.

OPTIMIZATION MODEL

To maximize the profit of a node V_i (enterprise) in G (V, E), a model to determine the optimal time period T to transfer knowledge is presented here.

Given that V_i and V_j are two nodes in G (V, E) and that V_i wants to transfer knowledge from V_j in time period T and that the expected total profits of V_i is denoted as $\Psi(T)$, we shall have $\Psi(T) = -K(T)+\xi(T)$, where, $\xi(T)$ is the expected profit of V_i gotten before knowledge transfer, $\xi(T)$ is the expected profit of V_i gotten after knowledge transfer and K(T) is the cost of absorbing knowledge from V_j. The calculation of $\xi(T)$, $\xi(T)$ and K(T) is derived as follows:

Expected profits before knowledge transfer: Assuming that the price of the product is p, then from hypothesis 2 and 3, the sales revenue in period n can be calculated by:

$$\begin{cases} pQ\phi(1+\theta_1)^n & n \le L1 \\ pQ\phi(1+\theta_1)^{L1}(1-\theta)^{n-L1} & n > L1 \end{cases} \tag{1}$$

From hypothesis 1, the marginal cost in period n is expressed as $MC\alpha''$. Using hypothesis 2, the total production costs in period n can be calculated by:

$$\begin{cases} Q\phi(1+\theta_1)^n MC\alpha^n & n \le L1 \\ Q\phi(1+\theta_1)^{L1}(1-\theta)^{n-L1} MC\alpha^n & n > L1 \end{cases} \tag{2}$$

Therefore, by subtracting the production cost in Eq. 2 from the sales revenue in Eq. 1, the profit in period n is calculated as follows:

$$\begin{cases} pQ\phi(1+\theta_1)^n - Q\phi(1+\theta_1)^n MC\alpha^n & n \le L1 \\ pQ\phi(1+\theta_1)^{L1}(1-\theta)^{n-L1} - Q\phi(1+\theta_1)^{L1}(1-\theta)^{n-L1} MC\alpha^n & n > L1 \end{cases} \tag{3}$$

By discounting the profit in period n to the beginning (with n = 0) at a discount rate r and summing up all the discount profits, the Discount Expectation of Profits (DEP) before knowledge transfer becomes:

$$\zeta(T) = \begin{cases} pQ\phi\sum_{n=1}^{T}(1+\theta_1)^n r^n - Q\phi MC\sum_{n=1}^{T}(1+\theta_1)^n \alpha^n r^n & T \le L1 \\ pQ\phi\sum_{n=1}^{L1}(1+\theta_1)^n r^n - Q\phi MC\sum_{n=1}^{L1}(1+\theta_1)^n \alpha^n r^n + pQ\phi(1+\theta_1)^{L1}\sum_{n=L1+1}^{T}(1-\theta)^{n-L1} r^n & \\ \quad - Q\phi MC(1+\theta_1)^{L1}\sum_{n=L1+1}^{T}(1-\theta)^{n-L1}\alpha^n r^n & T > L1 \end{cases} \tag{4}$$

Expected profits after knowledge transfer: If V_i transfers knowledge from V_j in a period of time T, based on hypothesis 2, the market share of V_i in a period of time T can be calculated as follows:

$$\begin{cases} \phi(1+\theta_1)^T & T \le L1 \\ \phi(1+\theta_1)^{L1}(1-\theta)^{T-L1} & T > L1 \end{cases} \tag{5}$$

From hypothesis 2 and 3, the market share of V_i will increase at a rate of ρ in the L periods immediately after the time period T and it will then decay at a rate of θ. Hence, the market share of V_i in period n can be denoted as follows:

$$\lambda(n,T) = \begin{cases} \phi(1+\theta_1)^T(1+\rho)^n & n \le L,\ T \le L1 \\ \phi(1+\theta_1)^T(1+\rho)^L(1-\theta)^{n-L} & n > L,\ T \le L1 \\ \phi(1+\theta_1)^{L1}(1-\theta)^{T-L1}(1+\rho)^n & n \le L,\ T > L1 \\ \phi(1+\theta_1)^{L1}(1-\theta)^{T-L1}(1+\rho)^L(1-\theta)^{n-L} & n > L,\ T > L1 \end{cases} \tag{6}$$

From hypothesis 4, the knowledge adopted by V_i in period T has been updated by β^T, which will make the marginal cost in period T reduce to $MC\beta^T$. If we renumber the periods after knowledge transfer as n starting from 1 to N, where, N is the life circle of the product defined in hypothesis 5, the marginal cost in period n becomes $MC\beta^T\alpha^n$. Hence, the total production cost in period n after knowledge transfer is $Q\lambda(n, T)MC\beta^T\alpha^n$. By subtracting the total production cost $Q\lambda(n, T)MC\beta^T\alpha^n$ from the sales revenue $pQ\lambda(n, T)$, the profit in period n after knowledge transfer is as follows:

$$\Pi^* = pQ\lambda(n,T) - Q\lambda(n,T)MC\beta^T\alpha^n \tag{7}$$

Discounting the profits in period n to the starting point by multiplying Eq. 7 by $r^T r^n$ and summing up all the N discount profits, the Discount Expectation of Profits (DEP) after knowledge transfer becomes:

$$\xi(T) = r^T\sum_{n=1}^{N}(pQ\lambda(n,T) - Q\lambda(n,T)MC\beta^T\alpha^n)r^n \tag{8}$$

Using Eq. 6 and 8, the expected profits after knowledge transfer can be expressed as follows:

$$\xi(T) = \begin{cases} pQ\phi(1+\theta_1)^T r^T \sum_{n=1}^{L}(1+\rho)^n r^n - MCQ\phi(1+\theta_1)^T \beta^T r^T \sum_{n=1}^{L}(1+\rho)^n \alpha^n r^n \\ \quad + pQ\phi(1+\theta_1)^T (1+\rho)^L r^T \sum_{n=L+1}^{N}(1-\theta)^{n-L}\gamma^n \\ \quad - MCQ\phi(1+\theta_1)^T (1+\rho)^L \beta^T r^T \sum_{n=L+1}^{N}(1-\theta)^{n-L}\alpha^n r^n & T \le L1 \\ pQ\phi(1+\theta_1)^{L1}(1-\theta)^{T-L1} r^T \sum_{n=1}^{L}(1+\rho)^n r^n - MCQ\phi(1+\theta_1)^{L1}(1-\theta)^{T-L1}\beta^T r^T \sum_{n=1}^{L}(1+\rho)^n \alpha^n r^n \\ \quad + pQ\phi(1+\theta_1)^{L1}(1-\theta)^{T-L1}(1+\rho)^L r^T \sum_{n=L+1}^{N}(1-\theta)^{n-L} r^n \\ \quad - MCQ\phi(1+\theta_1)^{L1}(1-\theta)^{T-L1}(1+\rho)^L \beta^T r^T \sum_{n=L+1}^{N}(1-\theta)^{n-L}\alpha^n r^n & T > L1 \end{cases} \tag{9}$$

Transfer cost: The transfer cost of node V_i is composed of two parts, the fixed transfer cost k defined in hypothesis 3 and the variable cost. The variable cost is related to the gap between the inside and outside knowledge level. We may compute the variable cost as $F(\alpha^T - \beta^T)$, where, F is a constant. After discounting the transfer cost to the starting point, it can be expressed as follows:

$$K(T) = (k + F(\alpha^T - \beta^T))r^T \tag{10}$$

The total discount expectation of profits model: Given that V_i and V_j are two nodes in G (V, E), V_i wants to transfer knowledge from V_j in time period T, the optimization problem of knowledge transfer will be to find the optimal time T to maximize $-K(T)+\zeta(T)+\xi(T)$. Therefore, the optimization model of knowledge transfer can be expressed as:

$$\max \psi(T) = -K(T) + \zeta(T) + \xi(T) \tag{11}$$

From Eq. 4, 9 and 10, the Eq. 11 becomes:

$$\mathrm{Max}\,\psi(T) = \begin{cases} pQ\phi\sum_{n=1}^{T}(1+\theta_1)^n r^n - Q\phi MC\sum_{n=1}^{T}(1+\theta_1)^n \alpha^n r^n + pQ\phi(1+\theta_1)^T r^T \sum_{n=1}^{L}(1+\rho)^n r^n \\ \quad - MCQ\phi(1+\theta_1)^T \beta^T r^T \sum_{n=1}^{L}(1+\rho)^n \alpha^n r^n + pQ\phi(1+\theta_1)^T (1+\rho)^L r^T \sum_{n=L+1}^{N}(1-\theta)^{n-L}\gamma^n \\ \quad - MCQ\phi(1+\theta_1)^T (1+\rho)^L \beta^T r^T \sum_{n=L+1}^{N}(1-\theta)^{n-L}\alpha^n r^n - (k + F(\alpha^T - \beta^T))r^T & T \le L1 \\ pQ\phi\sum_{n=1}^{L1}(1+\theta_1)^n r^n - Q\phi MC\sum_{n=1}^{L1}(1+\theta_1)^n \alpha^n r^n + pQ\phi(1+\theta_1)^{L1}\sum_{n=L1+1}^{T}(1-\theta)^{n-L1} r^n \\ \quad - Q\phi MC(1+\theta_1)^{L1}\sum_{n=L1+1}^{T}(1-\theta)^{n-L1}\alpha^n r^n + pQ\phi(1+\theta_1)^{L1}(1-\theta)^{T-L1} r^T \sum_{n=1}^{L}(1+\rho)^n r^n \\ \quad - MCQ\phi(1+\theta_1)^{L1}(1-\theta)^{T-L1}\beta^T r^T \sum_{n=1}^{L}(1+\rho)^n \alpha^n r^n + pQ\phi(1+\theta_1)^{L1}(1-\theta)^{T-L1}(1+\rho)^L r^T \sum_{n=L+1}^{N}(1-\theta)^{n-L} r^n \\ \quad - MCQ\phi(1+\theta_1)^{L1}(1-\theta)^{T-L1}(1+\rho)^L \beta^T r^T \sum_{n=L+1}^{N}(1-\theta)^{n-L}\alpha^n r^n - (k + F(\alpha^T - \beta^T))r^T & T > L1 \end{cases} \tag{12}$$

OPTIMALITY OF THE MODEL

The model itself: From Eq. 12, it is easy to see that $\Psi(T)$ is a piecewise continuous differential function of T. Therefore, $\Psi(T)$ can reach its maximum in a closed interval $1 \le T \le N$. That is to say, we can find the optimal knowledge transfer time in the life circle N of the product.

Moreover, since generally N is not very large, there is no need to find a higher and efficient algorithm to get the optimal solution, as exhaustive method is enough. Therefore, considering the powerfulness of the numerical

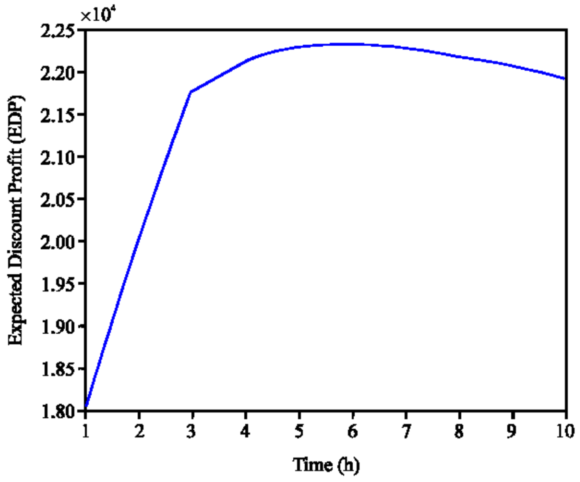

Fig. 1: Changes in total DEP

Table 1: Profit and cost of knowledge transfer

Periods	DEP before transfer	DEP after transfer	Transfer cost	Total DEP
1	1632	16750	333	18048
2	3275	17142	347	20070
3	4913	117209	347	21775
4	6438	16036	338	22136
5	7849	14777	322	22304
6	9146	13498	303	22341
7	10333	12243	282	22294
8	11415	11041	260	22196
9	12396	9910	238	22068
10	13284	8859	216	21927

calculation and simulation functions of Matlab, we only compiled a very simple program by Matlab. We made lots of experiments to test the model by adjusting its parameters.

Simulation experimental results: To simulate the practical innovation networks, a great deal of combinations of values of parameters of the model are chosen for testing. One of the sets of parameters considered is: $Q = 1000$, $\phi = 8\%$, $\theta_1 = 3\%$, $p = 60$, $\rho = 6\%$, $\theta = 3\%$, $MC = 40$, $k = 300$, $F = 1000$, $\alpha = 95\%$, $\beta = 88\%$, $N = 10$, $r = 0.9$. We assume the unit of the time period T is year.

Figure 1 and Table 1 show the experimental results of the model and a set of values of parameters used. The results in Table 1 and Fig. 1 imply that the discount expectation of profits is maximal at $T = 6$ and that the optimal knowledge transfer time is the 6th period.

3-DIMENSIONAL SIMULATION EXPERIMENTS

In order to find the influence of the parameters on the optimal knowledge transfer time, one of the parameters was set as a variable with time period set in turn. In this way, so many 3-dimensional simulation experiments were carried out at the same time. The 3-dimensional simulation results do not only further verify the correctness of the model but also provide decision support for enterprise management.

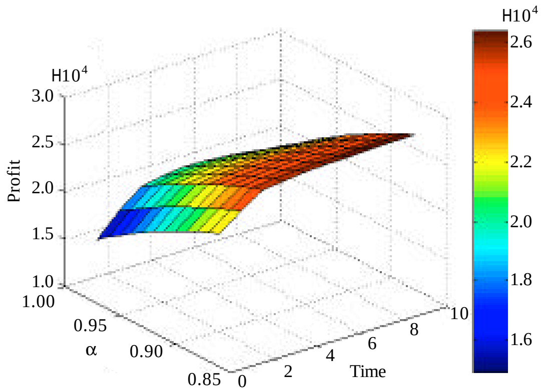

Fig. 2: Changes in EDP with α

Simulation with α as a variable: To find the influence of α on the optimal knowledge transfer time, all the parameters except α were set with the same values like the earlier mentioned. Figure 2 shows the Discount Expectation of Profits (DEP) with α varying from 0.88 to 0.99 and T varying from 1 to 10. From Fig. 2, it can be seen that the smaller the α the later the optimal knowledge transfer time becomes.

Simulation with β as a variable: To find the influence of β on the optimal knowledge transfer time, all the parameters except β were set with the same values as indicated in the previous section. Figure 3 shows the Discount Expectation of Profits (DEP) with β varying from 0.75 to 0.95 and T varying from 1 to 10. It can be seen that the smaller the β the earlier the optimal knowledge transfer time becomes.

Simulation with θ as a variable: To find the influence of θ on the optimal knowledge transfer time, all the parameters except θ were set with the same values as earlier mentioned.

Figure 4 shows the Discount Expectation of Profits (DEP) with θ varying from 0 to 0.15 and T varying from 1 to 10. From Fig. 4, it can be seen that the smaller the θ the later the optimal knowledge transfer time becomes.

Simulation with ρ as a variable: To find the influence of ρ on the optimal knowledge transfer time, all the

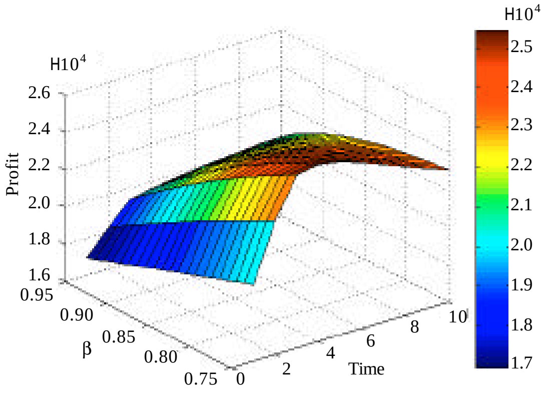

Fig. 3: Changes in EDP with β

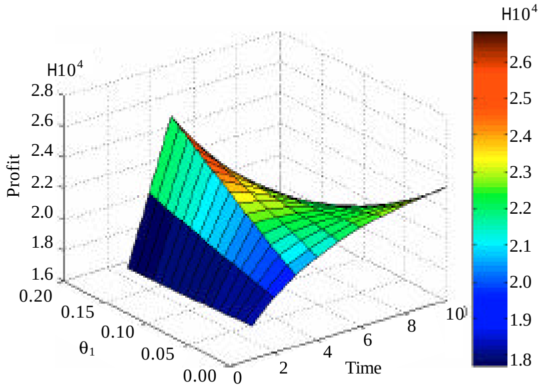

Fig. 4: Changes in EDP with θ

parameters except ρ were set with the same values as earlier mentioned. Figure 5 shows the Discount Expectation of Profits (DEP) with ρ varying from 0.03 to 0.15 and T varying from 1 to 10. From Figure 5, we can see that the smaller the ρ the later the optimal knowledge transfer time becomes.

DISCUSSION

There is no research on time optimization of knowledge transfer in innovation networks. There are only a few qualitative research results which provided various explanations for enhancing the efficiency of the knowledge transfer (Reagans and McEvily, 2003; Kotabe *et al*., 2003; Hoffmann, 2008). The proposed method in this study is quantitative, which can easily calculate the optimal time of knowledge transfer by imputing a set of parameters. The comparison between the proposed method and the current research results is shown in Table 2.

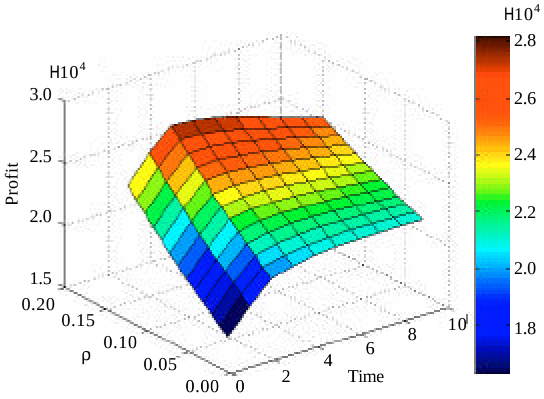

Fig. 5: Changes in EDP with ρ

Table 2: The comparison with current researches

Items	Current researches	Present proposed method
Method	Qualitative research	Quantitative research
Accuracy	Only give some policy recommendations	Can calculate the accurate optimal time of knowledge transfer

Table 3: Comparison of the results of simulations and the actual economic situations

Items	The results of simulations	The actual economic situation
Enhance α	The optimal time will delay	An enterprise will delay absorbing the knowledge
Enhance β	The optimal time will advance	An enterprise will adopt a high efficient knowledge earlier
Increase θ	The optimal time will advance	An enterprise will adopt the knowledge earlier
Increase ρ	The optimal time will advance	An enterprise will adopt the knowledge earlier

Meanwhile, from the 3-dimensional simulation experimental results, the influences of a factor on the optimal knowledge transfer time are predicted in the section above. To test the predicted influence trends, we compare them against the actual economic situations. From Table 3, we can see that all the predictions can be verified by the actual economic situations.

CONCLUSION

This study analysis the problem of time optimization of knowledge transfer in innovation networks. Based on the analysis of some important factors, a model to maximize the expected discount profit is presented. The validation of the model was done by setting the parameters and deriving the optimal time period of knowledge transfer. Simulation results show that the calculated results are in accordance with the actual economic situation. However, because of the complexity of knowledge transfer process and the diversity of influencing factors, some improvements are needed for the model to be more practical.

ACKNOWLEDGMENT

This study is supported by National Natural Science Foundation of China (No. 70572058, 70873038).

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