

Decision-Making Analysis of Enterprises' Adopting Innovation Technology

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Abstract: After analyzing the uncertainty of technology innovation diffusion (TID), this paper proposes the model of enterprises' TID based on geometric Brownian motion with jump, and analyzes the optional timing and influence of adopting innovation technology on TID by each parameter. The results show that enterprise should immediately adopts the technology when its market demand is greater than the optimal investment threshold of enterprise; changes of market environment is conducive to TID; increasing of market uncertainty and the expected rate of return will accelerate TID, and the increasing of market interest rate will inhibit TID.

Keywords: Uncertainty, Technology Innovation Diffusion, Geometric Brownian Motion, Model

1. Introduction

Technology innovation diffusion plays a pivotal role on promoting the upgrading and adjustment of industrial structure, increasing the marginal benefit of research funding, narrowing the gap between regional economic developments and improving the all-round progress of society, science, technology, economic and life. As American economist Schultz said: "without diffusion, innovative technology is unlikely to have an impact on economy" [1]. In view of this, it is of great significance to study the technology innovation diffusion.

Based on the overall reaction of the market, Bass (1969) established the famous Bass model that considered the number of total adopters as the variables [2]. This model added study on the mass media on the basis of the S-type model, and promoted the study on technology diffusion in the field of marketing. After that, a large number of scholars made improvements and established many S-type basic diffusion models. In early, the Bass model and its diffusion models are almost macro prediction models. However, scholars combine various theories and methods to develop a large number of micro decision models. Duan Maosheng, et al (2001) proposed a decision model for the adoption of a single potential user in the context of innovation in the case of certainty and uncertainty based on the micro decision theory

[3]. Steffens PR (2003) developed and tested a model for multiple-unit adoptions of durable goods based on the diffusion modeling tradition [4]. Based on the analysis of firms' stochastic adoption behavior, stochastic evolutionary models were built for substitutable innovation diffusion system [5]. MO Yun-qing, et al (2004) set up a probability model of innovation decision at the individual level and used the potential function to analyze the pay off of innovation [6]. HU Zhi-neng, XU Jiu-ping (2005) presented a multi-stage innovation product diffusion model with the theory of dynamic analysis, which includes the effect of price and advertising [7]. Xia Hui, Zeng Yong (2005) characterized the arrival of technology innovations as a Poisson jump process, under multiple future innovations and decreasing investment cost, firms' optimal investment strategies and diffusion of new technologies are studied by the cumulative probability distribution function of technologies adoption [8]. Carayannis EG, Turner E. (2006) proposed a model for security technology adoption and implementation through the examination of factors affecting adoption and implementation of Public Key Infrastructure (PKI) technology [9]. Huang Weiqiang, Zhuang Xintian (2007) explored the influence of the behaviors from innovation adoption individuals and the network structure on the innovation micro-adoption and macro-diffusion by ER stochastic graph model [10]. Emmanouilides Christos J. (2007) presented a new product

choice model in which individual agents were assumed to interact with each other across spatial hierarchies under random Gaussian laws [11]. ZHANG Jing-wei, et al (2010) constructed the optimal adoption timing decision model of new technology [12]. LU Mingkai, SHI Benshan (2011) constructed the real option pricing model with discrete time state combined with the new product diffusion characteristics using two binary tree methods, and analyzed the optimal timing of adoption of new technology [13]. HUANG Hai-yang, CHEN Ji-xiang (2012) established the evolutionary games model of the technology innovation diffusion of universities on the basis of the decision theory of technology innovation diffusion and analyzed the effect of adoption costs of universities technology and government subsidies on enterprises adoption decision [14]. The findings confirmed the offsetting roles of value and risk in affecting adoption and reveal the moderating effects of external market pressure in that both value and risk assume greater roles in affecting adoption as external market pressure increases [15]. Risselada Hans, et al (2014) analyzed the dynamic effects of social influence and direct marketing on the adoption of a new high-technology product [16]. Wang Zhanzhao, et al (2015) establishes the causal model of technology innovation diffusion system based on system dynamics, analyzes its important feedback loops and polarity [17]. From the scale of the potential adopters of networks, considering the potential adopters have influence on innovation adoption decision of local network, Huang Weiqiang (2015) established the innovation diffusion model. Considering the influence of local area networks on innovation adoption decision-making of consumer an innovation diffusion model from the micro to the macro was constructed based on the scale-free potential adopter networks [18]. Stummer Christian, et al (2015) introduced an agent-based model that deals with repeat purchase decisions, addressed the competitive diffusion of multiple products, and took into consideration both the temporal and the spatial dimension of innovation diffusion [19]. Montazemi Ali Reza, et al (2015) proposed two research models of factors affecting pre-adoption and post-adoption of the online banking and applied a two-stage random-effects meta-analytic structural equation modeling method to data collected from 25,265 cases from primary empirical studies of online banking adoption, findings show that ten factors affect consumers' adoption of the online banking [20]. In order to explore the emergence of low-carbon technological innovation diffusion by interactive mechanism of potential adoptive enterprises, Xu Yingying, Qi Liangqun (2016) took BA network as diffusion carrier and established potential adoptive enterprises' decision-making and low-carbon technological innovation diffusion models under market mechanisms and government regulation based on evolutionary game theory on networks. Studies showed that only when the additional income of low-carbon technological innovation adoption is more than input, the network can evolve to stable state of perfect diffusion [21]. Ma Yonghong (2016) established the innovation diffusion S-D model based on adopters decision-making and simulation analysis showed

that under the similar preferences of adopters, the trend of changes in network average degrees, network rewiring probability and the intensity of adopters preference were the same as the innovation diffusion efficiency, but the results would be opposite under the differentiation preferences of adopters [22]. Anand Adarsh, et al (2016) applied distance-based approach which was capable of computing the optimal model based on the distance of attribute value from the optimal, the analysis performed on two real life sales data sets depict that model in which awareness was following logistic pattern and motivation and adoption are following a constant pattern was ranked one [23].

Actually, the process of technology innovation diffusion is fraught with uncertainty, which exists in the market, the profit distribution and the diffusion environment. Especially the impact to the diffusion by the environmental uncertainty is severe, often with a mutation. Therefore, on the basis of the relevant literatures, this paper describes the sources of uncertainty during technology innovation diffusion, constructs the optimal adoption-timing decision model, and analyzes the impact to the diffusion from the parameters, by assuming that the profit of the enterprises adopting innovation technology follows a geometric Brownian motion with jumps.

2. Uncertainty During Technology Innovation Diffusion

The uncertainty during technology innovation diffusion comes from three aspects: the market, the profit distribution and the institutional environment.

2.1. Uncertainty from the Market

The ultimate test of innovative technology outcomes is the product market; the products made from the innovative technology have to reflect the market demand. So the uncertainty from the product market directly affects the profits of the enterprises adopting the technology and plays a key role during diffusion. It shows that at the beginning of an innovative technology generated, the innovators and potential adopters would be sure about neither the market acceptance of the product, or the influence that the product will bring to the existing market structure and the economic development. Therefore, the market prospect of the innovative technology is uncertain, and due to the lack of supply and demand information about this technology in the market, the enterprises have to invest much in educating consumers, training employees and so on, so there is tremendous risk for the potential adopting enterprises in establishing new production lines, training the staff, promoting products and so on. In additional, sometimes even if the enterprises have understood the basic needs of the market, they won't be sure about the way the demand changes and this situation can also bring uncertainty in the market. The uncertainty of the market displays in the following areas: when the enterprise adopts an innovative technology, whether or not its product can satisfy the need of consumers more, will the consumers accept this

new product, and how to make them accept it fast. If competition exists in the market, market uncertainty also includes if other enterprises will generate an innovative technology which can meet the market more, mainly referring to those major innovations.

2.2. Uncertainty from Profit Distribution

During the diffusion, after the potential enterprises adopt the innovative technology, the others also tend to rush to adopt this technology, and some enterprises even directly imitate the technology. Under this condition, the innovation profit will be inevitably divided by lots of enterprises, and the part that an enterprise can get depends on its position in the market, the cycle of the industry it's in, the enthusiasm degree of other enterprises to imitate the innovation, the knowledge property protection legislation and so on. So in the end the portion of the innovation profit that the adopters can get is highly uncertain.

2.3. Uncertainty from Institutional Environment

The diffusion of any innovative technology is inseparable from the diffusion system environment, which here mainly refers to the system, regulations and so on. Scilicet, it is the systematic arrangement by the government policies. In a sense, the time, space and scale of technology innovation are decided by the institutional environment and regulations rather than the technology itself or the market demand. Since the institutional environment and regulations are constituted by the government, it contains a large amount of uncertainty. For example, from the year 1979 to 1990, a number of worldwide oil crises broke out, and the Middle East countries cut down their oil export, which led to the soar of the oil price around the world and serious threatening to the energy industry and automotive industry. In such situation, the developed countries called for energy conservation, limited oil consumption, and encouraged to develop new energy. Benefited from such a policy, the new energy industry and energy-saving industry had developed rapidly, and the technology innovation diffusion in these fields had been greatly accelerated.

3. Technology Innovation Diffusion

3.1. Assumptions of the Model

According to the analysis in the previous section, it can be

$$V(Y_T) = E_T \left\{ \int_T^\infty [Y(\tau)D(Q)e^{-r(\tau-T)} - I]d\tau \right\} = \frac{Y(T)D}{r-u-(J-1)\lambda} - I \quad (5)$$

$V(Y_T)$ is also named as conversion option value.

According to vested pricing for jump-diffusion process studied by Merton in 1976 [24], $W(Y)$ satisfies the partial differential equation:

$$\frac{\partial W}{\partial Y}Yu + \frac{\partial W}{\partial t} + \frac{1}{2}\frac{\partial^2 W}{\partial Y^2}Y^2\sigma^2 - rW + \lambda E[W(JY, t) - W(Y, t)] - \lambda \frac{\partial W}{\partial Y}YE(J-1) = 0 \quad (6)$$

seen that the income of technology innovation diffusion is uncertain, and often with jumps, so this paper assumes that the enterprise adopts the technology innovation with a fixed cost I , and its revenue is decided by the inverse demand function in the product market and the uncertainty random variables at the same time, that is:

$$R(t) = Y(t)D(Q) \quad (1)$$

Where, $R(t)$ represents the revenue that the enterprise obtains after adopts the innovative technology. $D(Q)$ is a function representing the basic demand condition of its product after the enterprise adopts technology. In order to simplify the analysis, assuming this demand is a constant D . $Y(t)$ represents the demand shock, which possesses both uncertainty of the market and environment; in case of causing no confusion, Y is used to replace $Y(t)$, and assuming it obeys geometric Brownian motion with jumps.

$$dY(t) = uY(t)dt + \sigma Y(t)dz + (J-1)Y(t)dq \quad (2)$$

Among them, part $dY(t) = uY(t)dt + \sigma Y(t)dz$ is subject to the continuous diffusion process when there is no jump in the market random shock, u is drift term, it means expected rate of revenue, σ means volatility, dz is wiener increment.

The second half is a description of the jump process, where dq Poisson process, defined as is:

$$dq = \begin{cases} 0, \text{Probability } 1-\lambda dt \\ 1, \text{Probability } \lambda dt \end{cases} \quad (3)$$

That is, in a very small time interval, the probability of a jump occurs is λdt , $J-1$ is jump amplitude.

3.2. Construction of the Model

Assuming the risk free interest rate is r and the beginning time to adopt the innovative technology is T , when facing with uncertainty of market and policy, the value of the enterprise at moment t is:

$$W(Y_t) = \max_T E_t \left\{ \int_T^\infty [Y(\tau)D(Q)e^{-r(\tau-t)} - Ie^{-r(T-t)}]d\tau \right\} \quad (4)$$

Then its value at time T can be expressed as follows:

To make it simple, assuming the time to obtain profit is fixed, therefore $\partial W / \partial t = 0$, and the jump amplitude affected by the policy is a fixed constant, so the equation above can be simplified as:

$$\frac{\partial W}{\partial Y} Yu + \frac{1}{2} \frac{\partial^2 W}{\partial Y^2} Y^2 \sigma^2 - rW + \lambda[W(JY) - W(Y)] - \lambda \frac{\partial W}{\partial Y} Y(J-1) = 0 \quad (7)$$

$W(JY)$ is contained in the formula above, and usually there is no analytical solution, it can use Taylor expansion replace $W(JY)$ with $W(Y)$. That is:

$$W(JY) = W(Y) + \frac{\partial W}{\partial Y} (J-1)Y + \frac{\partial^2 W}{\partial Y^2} (J-1)^2 Y^2 \quad (8)$$

Then the ordinary differential equation of investment value is obtained as follows:

$$\frac{\partial W}{\partial Y} Yu + \frac{1}{2} \frac{\partial^2 W}{\partial Y^2} Y^2 \sigma^2 - rW + \lambda \frac{\partial^2 W}{\partial Y^2} Y^2 (J-1)^2 = 0 \quad (9)$$

This is a homogeneous Euler equation, and the general solution is $W(Y) = AX^{\beta_1} + BX^{\beta_2}$, where β_1 and β_2 are the roots of characteristic equation:

$$\left(\frac{1}{2} \sigma^2 + \frac{\lambda(J-1)^2}{2}\right) \beta(\beta-1) + u\beta - r = 0 \quad (10)$$

And it comes to:

$$\begin{cases} \beta_1 = \frac{1}{2} - \frac{u}{\sigma^2 + \lambda(J-1)^2} + \sqrt{\left(\frac{u}{\sigma^2 + \lambda(J-1)^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2 + \lambda(J-1)^2}} > 0 \\ \beta_2 = \frac{1}{2} - \frac{u}{\sigma^2 + \lambda(J-1)^2} - \sqrt{\left(\frac{u}{\sigma^2 + \lambda(J-1)^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2 + \lambda(J-1)^2}} < 0 \end{cases} \quad (11)$$

$\beta_2 < 0$ is meaningless, then there comes $W(Y) = AY^{\beta_1}$; according to the value-matching condition and smooth-paste condition, that is $W[Y^*] = V[Y^*]$ and $W_Y[Y^*] = V_Y[Y^*]$, there comes to:

$$\begin{cases} AY^{\beta_1} = \frac{Y^* D}{r - u - (J-1)\lambda} - I \\ A\beta_1 Y^{\beta_1-1} = \frac{D}{r - u - (J-1)\lambda} \end{cases} \quad (12)$$

The solution is

$$\begin{cases} Y^* = \frac{I\beta_1[r - u - (J-1)\lambda]}{D(\beta_1 - 1)} \\ A = \frac{I}{\beta_1 - 1} (Y^*)^{-\beta_1} \end{cases} \quad (13)$$

And the value of the enterprise is

$$W(Y) = \begin{cases} \frac{I}{\beta_1 - 1} \left(\frac{Y}{Y^*}\right)^{\beta_1}, & Y \leq Y^* \\ \frac{YD}{r - u - (J-1)\lambda} - I, & Y > Y^* \end{cases} \quad (14)$$

Y^* is the optimal investment threshold, when the demand fluctuation is less than the threshold, the enterprise will wait instead of adopt the innovative technology, otherwise, immediately adopt.

4. Model Analysis

4.1. Specific Analysis

Next we analysis each variables: $\sigma, u, r, \lambda, J, I, D$ for Y^* and W .

First, the analysis for Y^* . According to express (12):

$\ln Y^* = \ln[r - u - (J-1)\lambda] + \ln \beta_1 + \ln I - \ln(\beta_1 - 1) - \ln D$, it can get:

$$\begin{aligned} \frac{\partial \ln Y^*}{\partial \sigma} &= \frac{\partial \ln Y^*}{\partial \beta_1} \frac{\partial \beta_1}{\partial \sigma} = -\frac{\frac{\partial \beta_1}{\partial \sigma}}{(\beta_1 - 1)\beta_1} > 0, \quad \frac{\partial \ln Y^*}{\partial I} = \frac{1}{I} > 0, \\ \frac{\partial \ln Y^*}{\partial D} &= -\frac{1}{D} < 0 \end{aligned}$$

Due to the difficulty to tell the sign of $\partial \ln Y^* / \partial u$, $\partial \ln Y^* / \partial r$, $\partial \ln Y^* / \partial J$, $\partial \ln Y^* / \partial \lambda$ from their analytical expression, numerical simulation method is used to determine its impact on Y^* , let $\sigma = 0.2$, $\mu = 0.05$, $D = 20$, $J = 0.8$, $\lambda = 0.15$, $r = 0.1$, $I = 1$, Results are shown in Figure 1 to Figure 4. From Figure 1 it shows that $\partial Y^* / \partial u > 0$, which means that larger expected growth rate of revenue will lead to larger investment threshold. From Figure 2 it shows that $\partial Y^* / \partial r > 0$, which means that larger interest rate will lead to larger investment threshold too. From figure 3 it shows that $\partial Y^* / \partial \lambda < 0$, which means that weaker jump intensity will lead

to larger investment threshold. From figure 4 it shows that $\frac{\partial Y^*}{\partial \lambda} > 0$, which means that larger Poisson intensity will lead to larger investment threshold.

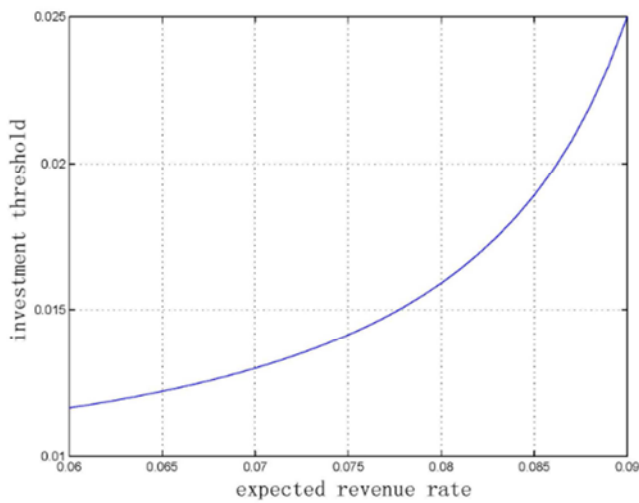


Figure 1. Influence on investment threshold by expected revenue rate.

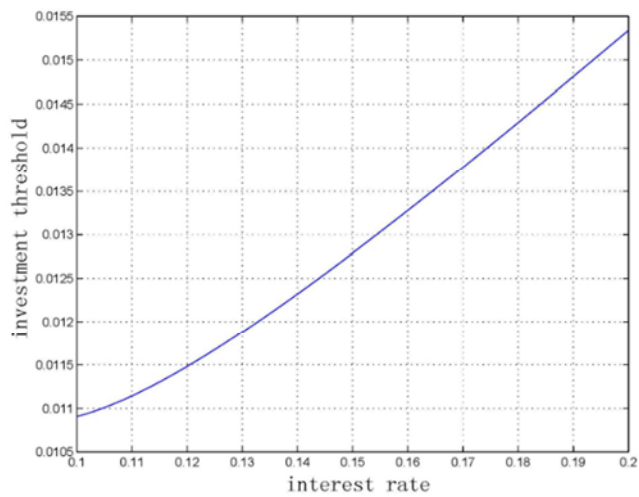


Figure 2. Influence on investment threshold by interest rate.

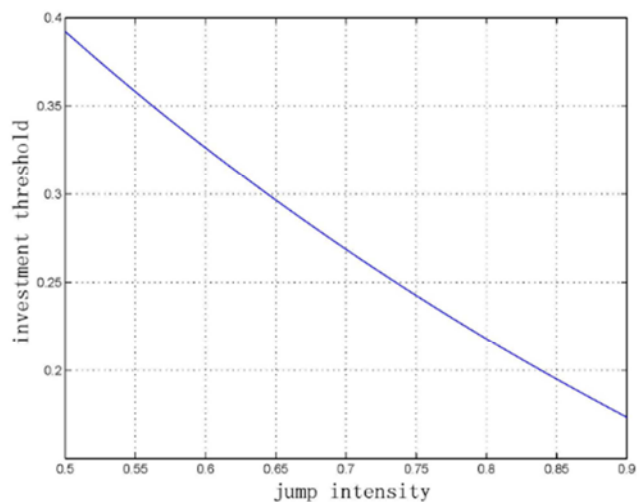


Figure 3. Influence on investment threshold by jump intensity.

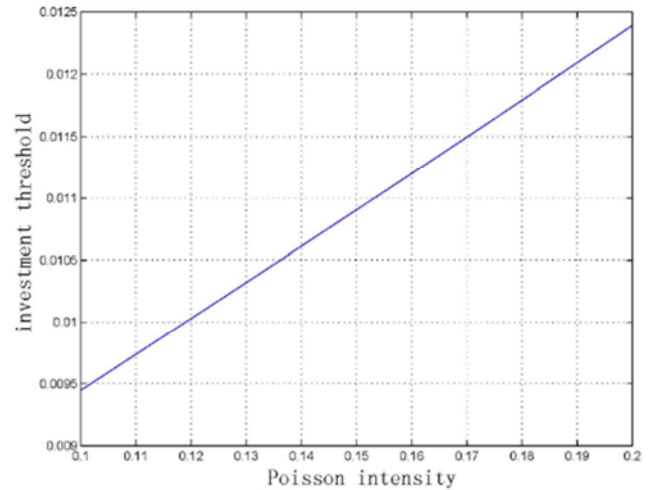


Figure 4. Influence on investment threshold by Poisson intensity.

Second, the analysis of W . With the similar analytical and numerical simulation methods, it can easily get: $\frac{\partial \ln W}{\partial \sigma} > 0$, $\frac{\partial \ln W}{\partial u} > 0$, $\frac{\partial \ln W}{\partial r} < 0$, $\frac{\partial \ln W}{\partial J} > 0$, $\frac{\partial \ln W}{\partial \lambda} < 0$, $\frac{\partial \ln W}{\partial I} < 0$, $\frac{\partial \ln W}{\partial D} > 0$. Then, volatility, jump intensity and rigid demand have positive effect on the enterprise's value while the other variables have reverse effect.

4.2. Analysis and Economic Implications

(1) Analysis of the results. All the analysis results above are summarized in Table 1:

Table 1. Influence on parameters from variables.

Variables Parameters	σ	μ	r	J	λ	I	D
Y^*	+	+	+	-	+	+	-
W	+	+	-	+	-	-	+

(2) Economic implications. The increased uncertainty leads to the increase of investment threshold and enterprise's value, which is consistent with the usual study result of real options. When the market is uncertain, the enterprises will choose to observe and make decisions later depend on the situation. In the case that the basic need of the market is fixed, the value of the enterprise will increase. The increased expected rate of revenue also leads to the increase of investment threshold and enterprise's value. Because if the expected rate of revenue increases, the enterprise will delay the adopting the technology until it can bring higher profit. The increased interest rates will increase the investment threshold while reduce the enterprise's value. Because the increased interest rates will increase the cost of capital, thereby inhibit investment. The decreased jump intensity will increase the investment threshold while decrease the enterprise's value. That is, when the drastic changes in the

market make the existing demand decrease, the enterprise will delay the investment, and the velocity of technology innovation diffusion will decrease, and then decrease the enterprise's value. The larger Poisson jump intensity means larger probability of dramatic changes, so the enterprise will tend to not adopt the innovative technology and thus decrease its value. The increased investment cost and the decreased demand will increase the investment threshold and reduce the enterprise's value, which is consistent with the common sense.

5. Conclusions

Based on the traditional real options, the paper introduces Poisson jump process to describe the shock on the diffusion by the dramatic environmental changes during technology diffusion. Then the timing for enterprises to adopt innovative technology, and the influences of key parameters are analyzed, and it is found that the increase of uncertainty will reduce the speed of technology diffusion, which implies that when it is not sure if the new technology will be accepted by the market, the enterprises often choose the existing technology rather than imitate the technology of leading enterprise. But the increase of expected growth rate will promote the technology innovation diffusion, and at this time the enterprises will rush to follow the leading enterprise, which can accelerate the dissemination of leading technology and drive the leading enterprise into a new round of innovation; and the expected growth rate is decided by the endorsement of the product by the market, namely product demand. The increase of market interest rates will slow down the technology innovation diffusion, because the increased interest rates will make enterprises more willing to leave the cash in the bank for the interests, and it also reduce the present value of future cash flows, which effaces enterprises' willing to invest. Last, the drastic change in the market environment is harmful for the technology innovation diffusion.

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