Advances in Management & Applied Economics, vol.2, no.1, 2012, 43-54
ISSN: 1792-7544 (print version), 1792-7552 (online)
International Scientific Press, 2012

Product Innovation Risk Management based on Bayesian Decision Theory

Yingchun Guo[1]

Abstract

Innovation is an inexhaustible force for the prosperity of one nation, and also the life source of enterprises. Product innovation is an important aspect of innovation. However, the product innovation activities has high-risk characteristics. Enterprises have to perform scientific and effective product innovation risk management. Based on a general introduction of Bayestian Decision Theory principle, the author studied the practices of product innovation in enterprises. The paper discussed how to use Bayesian Decision Theory to achieve quantitative innovation-risk management in product innovation: based on the description of three elements for product innovation risk management, the author discussed the process of bayesian risk decision-making in product innovation. Thus to providing references for scientific decision of innovation activities in enterprises.

[1] College of Mathematics & Computer Seience, Hebei University, China.
e-mail: guoyc@hbu.cn

Article Info: *Received* : December 2, 2011. *Revised* : January 15, 2012
Published online : February 28, 2012

JEL classification numbers: O31

Keywords: Product Innovation, Innovation Risk, Risk Management, Bayesian Decision Theory

1 Introduction

Innovation is the soul of a nation's progress, an inexhaustible force for the prosperity of a nation, and the life source of enterprises [1]. Without innovations, enterprises would not be able to upgrade the production structure. With weakening competitiveness, enterprises will die. However, innovation is a "double-edged sword", with characteristics of high potentials, high inputs, high returns, and high risks. Particularly, high risks from technologies, market, and management frustrate or even kill many innovation activities, which may even threaten the healthy development of human society. Therefore, to manage the innovation risks is significant.

Currently, most researches on innovations are about methods and modes that promote enterprises to develop independent innovations, seldom focus on innovation risks. [2] built an application framework for high-tech enterprises implementing overall risk management. [3] proposed a synthesized risk management mode for enterprises' coorperative innovations based on the meta-synthesis method. [4] put forward the risk management strategy in the process of technological innovation use to achieve effective risk prevention. All these literatures were qualitative studies on different stages of risk management.

In the theoretical field, there are quantitative researches on innovation risk management. [5] proposed the synthesis evaluation method and applied it to the risk evaluation of enterprises' technological innovation. [6] built a risk pre-warning system for enterprises' technological innovation projects. [7] proposed a production innovation program driven by market or customer data.

These researches promoted the scientific decision of technological risk management, but the application is unsatisfying. On one hand, these methods are too complicated to use in enterprises. On the other hand, most quantitative studies focus on the risk evaluation, but seldom on risk decision.

Risk decision-making is to make decision according to incomplete information. According to the objective of risk management, with basis of risk identification and risk evaluation, make reasonable choice and combination of different risk management methods, and offer a specific program for risk management. Faced high risks from technologies, market, and management, enterprise managers should master the scientific and feasible risk decision-making method, managing innovation risks effectively.

Bayesian approach is a powerful tool for risk decision-making [8]. Due to its convenience and easiness, this approach is applying in many fields. [9] used the Bayesian Decision technology to support the new product development management. [10] applied the Bayesian network method to the risk evaluation in new product R & D. [11] proposed a Bayesian solution for enterprises predicting the strategic marketing management decision. [12] built a Bayesian model to achieve dynamic knowledge update, in order to deal with the supply uncertainties and risks. This paper is to explore the effective quantitative risk decision-making method, in order to help enterprise managers to achieve effective innovation risk management.

2 An Introduction of Bayesian Decision Theory

Risk decision-making decision runs through the whole risk management process. By analyzing risks and losses scientifically, it can help to choose the reasonable risk management techniques and methods and finally get the most satisfying solution from several options. Every risk decision-making includes three elements: the state group consisted of different natural status, the action group consisted of a set of actions taken by decision makers, and the description of utility or losses from different combinations of statues and actions. From the three elements, we can get different risk conditions. Once the decision maker makes a decision with uncertain result, it means certain risk. The risk decision-making needs to get changeable market information by increasing inputs. Based on mastering various natural conditions in time, use the collected information reasonably, and select the decision scientifically, reducing risks, and improving economic and social benefits. In risk decision-making, the accuracy of estimation of natural conditions can directly affect the expected returns. In order to make better decision, it needs to update the information in time. After getting new information, we can revise the original estimated probability of emergence of certain natural condition, and use the revised probability distribution to make new decision. Because the probability correction is based on the Bayesian Theorem in probability theory, this decision is called Bayesian Decision.

3 Product Innovation Risk Management Cases

3.1 Three Elements for Innovation Risk Management Decision

3.1.1 The Set of Natural States

The comprehensive evaluation on innovation activity is $N = \{N_1, N_2, \cdots, N_m\}$. For instance, N_1 stands for best, N_2 stands for better, …, and N_m stands for worst. Experts give the prediction posterior probability of each state $P(N_i), (i = 1, ..., m)$. (See Table 1).

Table 1: Utility

State&probability \ Utility \ Program	d_1	d_2	$\cdots$	d_n
N_1 : $P(N_1)$	u_{11}	u_{12}	$\cdots$	u_{1n}
N_2 : $P(N_2)$	u_{21}	u_{22}	$\cdots$	u_{2n}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
N_m : $P(N_m)$	u_{m1}	u_{m2}	$\cdots$	u_{mn}

3.1.2 The Set of Actions

The action toward innovation activity is $D=\{d_1,d_2,\cdots,d_n\}$. Here d_1 stands for high investment, such as more investment in R & D, new production equipment, and new product. d_2 stands for medium investment, such as medium investment in R & D, and changes of product functions. d_3 stands for low investment, such as changes of production techniques, and better product quality. d_4 stands for no investment in innovation, such as only changes in packages or more advertisements.

3.1.3 The Matrix of Descriptions of Utility or Losses

$U=(u_{ij})_{mn}$. Here, $u_{ij}\in[-100,100]$ is the economic utility that can be evaluated by money, or the utility function evaluated by non-monetary factors. Here, we suggest the second meaning, because innovation activities can not only generate economic benefits, but also social benefits, so as to bring intangible assets and long-term interests for enterprises. Here, the utility function can be measured by the satisfaction degree, such as enterprises' satisfaction degree, customers' satisfaction degree, expert scoring, and other comprehensive scores.

3.2 Description of Product Innovation Risk

Suppose an enterprise starts a new product R & D. There are five states of comprehensive evaluations on economic utility and social benefits $N = \{N_1, N_2, N_3, N_4, N_5\}$. Here, N_1 stands for best, N_2 stands for better, N_3 stands for medium, N_4 stands for worse, and N_5 stands for worst. According to the data analysis of the market survey and the expert prediction, the probability distribution of each state is $P(N_1)$=0.2, $P(N_2)$=0.4, $P(N_3)$=0.2, $P(N_4)$=0.15, $P(N_5)$=0.05. The enterprise has four options $D = \{d_1, d_2, d_3, d_4\}$. d_1 stands for high investment, d_2 stands for medium investment, d_3 stands for low investment, and d_4 stands for no investment. The utility of four options under different states is in Table 2.

Table 2: The expected utility of investment

State&probability / Utility / Program	d_1	d_2	d_3	d_4
$N_1 : P(N_1)$=0.2	u_{11}=100	u_{12}=70	u_{13}=60	u_{14}=-80
$N_2 : P(N_2)$=0.4	u_{21}=70	u_{22}=80	u_{23}=70	u_{24}=-60
$N_3 : P(N_3)$=0.2	u_{31}=50	u_{32}=60	u_{33}=80	u_{34}=-40
$N_4 : P(N_4)$=0.15	u_{41}= -20	u_{42}=10	u_{43}=30	u_{44}=-20
$N_5 : P(N_5)$=0.05	u_{51}=-100	u_{52}=-80	u_{53}=-40	u_{54}=0

Data description: the expected utility declines along with the diminishing prospect of market state. For instance:

u_{11}: under the high investment and best market conditions, the economic utility and social benefits reach the highest. The expected utility u_{11}=100; u_{21}: under the high investment and better market conditions, the economic utility and social benefits are high. The expected utility u_{21}=70; u_{31}: under the high investment and ordinary market conditions, the economic utility and social benefits are medium. The expected utility is u_{31}=50; u_{41}: under the high investment and worse market conditions, the economic utility and social benefits are worse. The expected utility is u_{41}=-20. u_{51}: under the high investment and worst market conditions, the enterprise suffers from serious losses. The expected utility is u_{51}=-100.

Here, please focus on the last line. If the enterprise takes the no investment strategy, the expected utility will be negative. For instance, u_{14}: the enterprise does not invest, though the market conditions are good. It will make the enterprise lose potential economic utility and social benefits. The expected utility u_{14}=-80; u_{54}: the enterprise does not make innovation investment and the market conditions are bad. Then, there is no economic benefit or social benefit. The expected utility u_{54}=0.

3.3 The Bayesian Risk Decision-Making Process

3.3.1 Prior Analysis

According to the probability of natural state and the expected utility (see Table 2), by following the law of expectation, calculate the expected utility of each program. $E\left(d_j\right)=\sum_{i=1}^{5}P\left(N_i\right)u_{ij}$, $j=1,...,4$. Accordingly, the optimal expectation for the optimal program is $\max_j E\left(d_j\right)=E\left(d_k\right)=EMU$.

For instance, $E\left(d_1\right)$ =0.2*100+0.4*70+0.2*50+0.15*(-20)+0.05*(-100)=50; similarly, $E\left(d_2\right)$=55.5, $E\left(d_3\right)$=58.5, $E\left(d_4\right)$=-51. Then, the optimal decision and the optimal expected utility is EMU=$E\left(d_3\right)$=58.5 . It means that the enterprise can take the low-investment strategy if only with the prior information.

3.3.2 Prediction Posterior Analysis

In prediction posterior analysis, estimate the value of complete information firstly. As the prediction of complete information is in the state N_k, it becomes the decision-making under certainty. Apparently, the optimal program is $\max_j \{u_{kj}\}$. Then, with complete information, the maximum expected utility from decision-making is:

$EUPI = \sum_{k=1}^{5} P(N_k) \max_{1 \le j \le 4} \{u_{kj}\}$ =0.2*100+0.4*80+0.2*80+0.15*30+0.05*0=72.5.

Therefore, the value of complete information $EVPI = EUPI - EMU$ =72.5-58.5 =14. It means the value of complete information is equal to 14 units of utility.

3.3.3 Posterior Analysis

(1) *Supplement new information.* According to the market conditions, investigate, explore, and consult the five states X_1 (excellent), X_2 (better), X_3 (medium), X_4 (worse), and X_5 (worst), and predict which one will appear. Meanwhile, get the conditional probability $P(X_j | N_i)$, which is the probability of predicting the emergence of X_j when the natural state N_i actually appears. (See Table 3).

Table 3: The likelihood ratio

Likelihood ratio $P(X_j \| N_i)$	X_1	X_2	X_3	X_4	X_5
$N_1 : P(N_1)$=0.2	0.5	0.2	0.15	0.1	0.05
$N_2 : P(N_2)$=0.4	0.2	0.5	0.2	0.05	0.05
$N_3 : P(N_3)$=0.2	0.1	0.2	0.5	0.15	0.05
$N_4 : P(N_4)$=0.15	0.05	0.15	0.2	0.5	0.1
$N_5 : P(N_5)$=0.05	0.05	0.1	0.15	0.2	0.5

(2) *Revise the probability*. Based on the prior probability $P(N_i)$ (i=1,2,…,5) and the conditional probability $P(X_j|N_i)$ (i=1,2,…,5; j=1,2,…,5), calculate the probability distribution of X_j: $P(X_j)=\sum_{i=1}^{5}P(N_i)P(X_j|N_i)$.

For instance, $P(X_1)=$ 0.2*0.5+0.4*0.2+0.2*0.1+0.15*0.05+0.05*0.05=0.21. Similarly, $P(X_2)=$ 0.3075, $P(X_3)=$ 0.2475, $P(X_4)=$ 0.155, and $P(X_5)=$ 0.08. Use the Bayesian formula to calculate the revised probability of N_i, namely the posterior probability (see Table 4):

$$P(N_i|X_j)=\frac{P(N_i)P(X_j|N_i)}{P(X_j)}, \quad (i=1,2,\ldots,5;\ j=1,2,\ldots,5).$$

Table 4: The posterior probability

Posterior probability $P(N_i\|X_j)$	N_1	N_2	N_3	N_4	N_5
X_1	0.4762	0.3810	0.0952	0.0357	0.0119
X_2	0.1301	0.6504	0.1301	0.0732	0.0163
X_3	0.1212	0.3232	0.4040	0.1212	0.0303
X_4	0.1290	0.1290	0.1935	0.4839	0.0645
X_5	0.1250	0.2500	0.1250	0.1875	0.3125

(3) *Posterior decision.* Suppose the supplement information predicts the appearance of state X_k . Use the posterior revised probability distribution $P(N_i|X_k)$ (i=1,2,…,5) to calculate the expected utility of each program. By following the law of expectation, make the decision. Then,

$$E(d_j|X_k)=\sum_{i=1}^{5}P(N_i|X_k)u_{ij}, \quad (j=1,2,\ldots,5,\ k=1,2,\ldots,5).$$

For instance, if the market survey shows that the market condition is X_1, calculate the expected utility of d_k (see Table 5).

$E\left(d_1 \middle| X_1\right)$ =0.4762*100+0.381*70+0.0952*50+0.0357*(-20)-0.0119*100=77.14. Similarly, there is $E\left(d_2 \middle| X_1\right)=$ 68.93, $E\left(d_3 \middle| X_1\right)$ =63.45, $E\left(d_4 \middle| X_1\right)=$ -65.48. Here, as the market condition is better, the enterprise can take the stategy d_1. The maximum expected utility is $E\left(d_1 \middle| X_1\right)=77.14$.

Similarly, As the market condition is X_2, the maximum expected utility is $E\left(d_2 \middle| X_2\right)=68.37$; As the market condition is X_3, the maximum expected utility is $E\left(d_3 \middle| X_3\right)=64.65$; As the market condition is X_4, the maximum expected utility is $E\left(d_3 \middle| X_4\right)=44.49$; As the market condition is X_5, the maximum expected utility is $E\left(d_3 \middle| X_5\right)=28.13$.

Table 5: The posterior expected utility

Posterior expected utility $E\left(d_j \middle| X_k\right)$	d_1	d_2	d_3	d_4
X_1	77.14	68.93	63.45	-65.48
X_2	61.95	68.37	65.28	-56.10
X_3	49.49	57.37	64.65	-47.68
X_4	15.48	30.65	44.19	-35.48
X_5	1.25	13.13	28.13	-33.75

(4) *Calculate the value of supplement information.* According to the calculated supplement information, predict the probability of each status $P\left(X_i\right)$ (i=1,2,…,5). Calculate the maximum expected utility in posterior analysis:

$$EMU^{*}=\sum_{i=1}^{5} P\left(X_i\right) E\left(X_i\right)$$

=0.21*77.14+0.3075*68.37+0.2475*64.65+0.155*44.19+0.08*28.13=62.325

Apparently, after getting the supplement information, the expected utility rises: $EMU^{*} - EMU$ = 62.325-58.5=3.825. The value of supplement information is 3.825 unit of utility. Then, compare the value of supplement information and the cost for acquiring the information, and make the right decision.

4 Conclusion

The innovation risk management is critical for the survival and the development of enterprise. In this paper, taking the product innovation activity for instance, the author discusses the innovation risk management based on Bayesian Risk Decision-Making. Here, one point should be noted particularly: the repetitive application of Bayesian Risk Decision-Making can help the enterprise to carry out the dynamic risk management of innovation activities and adapt to the changing market conditions, achieving the scientific management of innovation risks.

ACKNOWLEDGEMENTS. This paper is a part of the project “Research on Innovation Risk Management Mechanism of Industrial Chain” of Hebei Soft Science Program of China.

References

[1] S. Cheng, On the construction of an innovative country, *China Soft Science*, **12**, (2009),1-14.

[2] F. Xiao and J. Hao, On the ERM implementation framework of high-tech enterprises, *Scientific Management Research*, **28**(2), (2010), 66-69.

[3] R. Liu and K. Wang, Research on integrated management for enterprise's cooperation innovation, *Science and Technology Management Research*, **10**, (2009), 339-340.

[4] Y. Miao, Enterprises in the process of technological innovation risks and prevention strategy, *Science and Technology Management Research*, **7**, (2010), 1-3.

[5] Z. Song, S. Wang and Z. Liu, Application of ANP-GRAP integrating method for risk evaluation in enterprises' technological innovation, *Science of Science and Management of S. & T*, **1**, (2010), 55-58.

[6] X. Li, J. Xu and J. Yan, Study on the construction of risk early warning system for enterprise technological innovation projects, *Journal of Sichuan University* (*Social Science Edition*), **5**, (2010), 88-95.

[7] K. Andrew, Innovation: a data-driven approach, *International Journal of Production Economics*, **122**(1), (2009), 440-448.

[8] B. Richard, A unified Bayesian Decision Theory, *Theory and Decision*, **63**(3), (2007), 233-263.

[9] P.V. Jacobus and C.V.W. Cornelis, New product development with dynamic decision support, *International Journal of Innovation and Technology Management*, **6**(2), (2009), 155-167.

[10] C. Kwai-Sang, T. Da-Wei, Y. Jian-Bo, etc, Assessing new product development project risk by Bayesian network with a systematic probability generation methodology, *Expert Systems with Applications*, **36**(6), (2009), 9879-9890.

[11] L. Paul and G.L. Reynolds, Predictive strategic marketing management decisions in small firms: A possible Bayesian solution, *Management Decision*, **45**(6), (2007), 1038-1057.

[12] C. Min, X. Yusen and W. Xinlei, Managing supply uncertainties through Bayesian information update, *IEEE Transactions on Automation Science and Engineering*, **1**, (2010), 24-36.