 doi:10.20944/preprints201807.0563.v1

Peer-reviewed version available at *Risks* **2018**, *6*, 98; doi:10.3390/risks6030098

Optimum technology product life cycle technology innovation investment - Using compound binomial options

Chuan-Chuan Ko, Assistant Professor
Department of Business School
City College of Dongguan University of Technologic
Address: No. 1, Wenchang Road, Liaobu Town, Dongguan, Guangdong, China
e-mail: kochuanchuan@qq.com

Tyrone T. Lin, Professor
Department of International Business,
National Dong Hwa University
Address: No. 1, Sec. 2, Da Hsueh Rd. Shoufeng, Hualien 97401, Taiwan, R.O.C.
e-mail: tjlin@gms.ndhu.edu

Fu-Min Zeng, Administrator
Marketing Department,
Data Communications Branch, Chunghwa Telecom Co., Ltd.
Address: No. 21-3, Section 1, Xinyi Road, Zhongzheng District, Taipei City, Taiwan, R. O. C.
e-mail: mi650129@cht.com.tw

Chien-Yu Liu, Assistant Professor
Department of Food and Beverage Management
Jinwen University of Science & Technology
Address: No. 99, Anzhong Rd., Xindian Dist., New Taipei City 23154, Taiwan, R. O. C.
e-mail:liuvincent@just.edu.tw

Correspondence Author:

Chuan-Chuan Ko, Assistant Professor

Department of Business School, City College of Dongguan University of Technologic

Tel:+86-13802456920

E-mail: kochuanchuan@qq.com

Optimum technology product life cycle technology innovation investment- Using compound binomial options

Abstract

The purpose of this paper is to evaluate the timing of innovative investment in technology product life cycles using a compound binomial option with management flexibility. Considering the business cycles changes in the macroeconomic will affect consumer purchasing power. The focus is how to evaluate the optimal investment strategy and the project value. It was applied to different product stages (three stages including production innovation, manufacture innovation, and operation innovation) and factored to different risks to build a technology innovation strategy model. An aim of this study is the options premium of the best strategy timing for each innovation stage. Its application of the compound binomial options for the manufacture innovation will only be considered after the execution of the production innovation. The same condition is applied to the operation innovation, which will only be considered after the execution of the manufacture innovation. Then, this paper constructs the dynamic investment sequential decision model, assesses the feasibility of an investment strategy, and makes a decision on the appropriate project value and options premium for each stage under the possible change of Gross Domestic Product (GDP). This paper investigates the product life cycle innovation investment topic by using the compound binomial options method and will provide a more flexible strategy decision compared with other trend forecast criteria.

Keywords: Technological innovation; cloud computing; Compound binomial options; Investment risk; Uncertainty.

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

1. Introduction

Illegal hackers invading information transmissions caused big losses to firms, due to the increasing high volume of internet transactions. Information technology security has become an important issue for enterprises. More firms will abundantly invest into cloud technology in the future. Information technology security could be considered as the most important issue for cloud technology development; therefore, the demand for dynamic password codes would increase. This research would aim at dynamic password code technology innovations.

In view of the short life cycles of technology products, businesses must focus on speed, innovation and the extent of customer acceptance. Firms must have the ability to quickly respond to customer preferences and required changes in order to increase market share. De Kluyver (1997) proposed that innovation could extend product life cycles. So product innovation was in fact an important part of extending product life cycles. In general, when assessing investment strategies, firms not only had to consider their own resources, but also had to consider the uncertainties of the investment risks of the external environment, emerging competitors, and economic cycles. Therefore, this paper utilizes the opportunity of assessing technology product innovation investment to offer references to decision makers in the presence of competitive behavior for determining when to assume the leadership advantage, dominate the market and force competitors to drop out, and at the same time, consider how to avoid risks.

This paper applied the compound binomial options model to the exploration of innovation investment strategies of high-tech products. A compound option is an option whose value is decided by the values of other options (Copeland and Antikarov, 2001). While financial risk assessment is one of the important factors to consider when making investment decisions for products in the technology industry, in general, the net present value (NPV) method is the most commonly adopted assessment method used for investment strategies. However, the method is

Peer-reviewed version available at *Risks* **2018**, *6*, 98; doi:10.3390/risks6030098

more suitable for a static investment environment because the NPV method lacks the considerations required for a dynamic investment environment and ignores the value of managerial flexibility. The real options approach (ROA), which takes managerial flexibility value into its strategic investment considerations, is a more applicable assessment method for a highly uncertain technology product investment project. In an uncertain and complex investment environment, a manager's investment strategy should include a dynamic strategic analysis model so the ROA is more adaptive than the conventional NPV method in a complex investment environment (Myers, 1977; Dixit and Pindyck, 1994).

Lin (2010) used the ROA to determine if a company required a technology innovation investment project for market entry and market exit, evaluated the decision values and project values of the market exit phase, maintaining the existing technology phase, and adopted the advance technology phase. It also applied the market entry and exit critical values to reflect the need for technology innovation, offering a company the optimal investment strategies. Verdu et al. (2012) showed that the ROA improved the level of product technological innovation. This paper found that this development would increase when the level of uncertainty of the environment is higher. Wang and Yang (2012) used the ROA to assess research and development projects by dividing a drug development process into three stages, and then studying the differences in the risks presented in each stage. The study assesses the value of each stage of the R&D process by using the ROA. Cassimon et al. (2011) observed that the compound real options were permitted for phase-specific volatility estimates. This study reported that phase-specific volatilities can be estimated for project managers. Cheng et al. (2011) used the binomial model approach, which was modified from sequential compound options, to analyze future GDP changes based on past historical data, their resulting impact on electricity demand, and their influence on the development path of clean energy investment strategies. This model takes into consideration the effects of future environment changes and

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

policy lead time. The results may provide a reference for policy making for government organizations with longer than normal lead time and companies with capital-intensive investments. Lo Nigro et al. (2014) used the ROA in the open innovation field in order to push firms to take on the innovation model. Daming et al. (2014) pointed out that many researchers pay more attention to new technology development modes, which is completely different from the incremental technological innovation of the past. This paper constructed a real option game model for the analysis on game equilibrium that a company will have a strong motivation for implementing radical innovation only when market reaction to its products is moderate. Koosha and Albadvi (2015) used the real options approach to construct consumer life cycle values. Their research points out that most measures of consumer life cycle value cannot be considered in an uncertain environment. Numerical analysis shows that traditional measurement methods ignore some considerable value, mainly the value of the decisive factors of management decision makers. Ball et al. (2015) used the ROA to establish a flexible decision model under agent uncertainty. Morreale et al. (2017) used game options to shape the timing of biopharmaceuticals and biotechnology alliances. Lee and Lin (2018) used the real option approach method to construct a three-stage management decision model. They analyzed the frequency of fires from a dynamic point of view, examined the fire damage data of an international city for ten years, and proposed the best time to purchase fire hazards or install fire safety systems. Liu et al. (2017) adopted the pricing of n-fold compound options with barriers. They developed a generalization of the compound barrier option with a stochastic interest rate to capture the interest rate risk. Morozko et al. (2018) suggested that the method of choice of ROA can be used to make the most reasonable substitution decision. Detemple and Kitapbayev (2018) used the ROA when the investment cost changes with the random jump process. The performance of optimal investment boundaries and valuation components are inspected. Three valuation formulas are derived and all are in closed form. Their proposed

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 July 2018 doi:10.20944/preprints201807.0563.v1

Peer-reviewed version available at *Risks* **2018**, *6*, 98; doi:10.3390/risks6030098

binomial model allowed us to explore dynamic changes in various options for the development of small organizations to predict changes in financial results. With the help of the Bayes criterion, the calculation of the optimality of the adopted development strategy is proposed.

2. The model

This paper aims to explore the process of deciding whether to adopt technology innovation on a product when facing the uncertainty of environmental changes. During this process, a change in the economic cycle, which is a part of the overall economy, affects consumer purchasing power, and the GDP, which represents future economic growth, is uncertain. The study takes into account the characteristics of product life cycles in the introductory, growth, and maturity stages, and assesses the optimal investment strategies of each stage and project values, as well as the options premiums of the decision-making points.

2.1 Assumptions

This study assumes that the changes in GDP affect the purchase and consumption abilities of its citizens, and in turn impact production and revenues. This study analyzed historical data to find possible future GDP occurrences and determine their impact on consumer purchasing power and their further impact on investment strategy development paths concerning their product development in technology innovation. Assume that $t=0$ is the GDP base stage. u and d are defined as the upward and downward multipliers of the variable GDP in the next period, respectively, and $u \times d = 1$ is satisfied. Let s denote the three stages of technology innovation and $s =$ *I, II, III* denote the first stage, the second stage, and the third stage respectively. Let r denote the risk-adjusted discounted rate (Lin, 2009; Lin and Huang, 2011), complying with the natural constraints of $u > 1+r > d$. The possible growth path of risk-adjusted probability is $p=(e^{n\times r}-d)/(u-d)$ (Copeland and Antikarov, 2001); the decline

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 July 2018 doi:10.20944/preprints201807.0563.v1

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

path of risk-adjusted probability is $1-p$ $(0 \le p \le 1)$. Then this paper has the GDP change path, the relevant path ratio distribution, and the corresponding GDP nodes of each time frame as shown in Figure 1 (Copeland and Antikarov, 2001; Cheng et al., 2011):

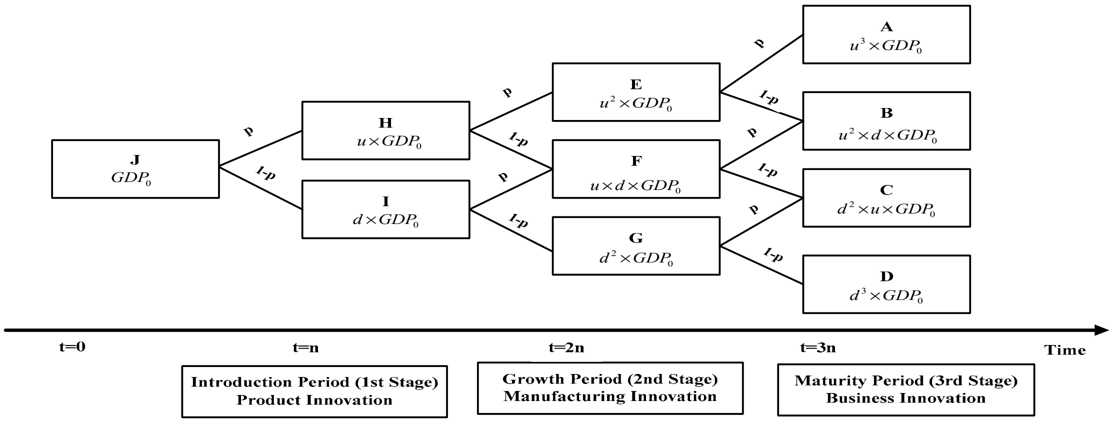

Figure 1. GDP change path

In Figure1 GDP change path, this study assumes GDP_i is the GDP of i node, where $i = A, B, C, D, E, F, G, H, I, J$ and $GDP_J = GDP_0$ is the GDP of J node. Then the GDP of H node is $GDP_H = u \times GDP_0$. In addition, the GDP of I node is $GDP_I = d \times GDP_0$. Similarly, the GDP of each node is $GDP_E = u^2 \times GDP_0$, $GDP_F = u \times d \times GDP_0$, $GDP_G = d^2 \times GDP_0$, $GDP_A = u^3 \times GDP_0$, $GDP_B = u^2 \times d \times GDP_0$, $GDP_C = u \times d^2 \times GDP_0$, and $GDP_D = d^3 \times GDP_0$ respectively. The expected future revenue of the product corresponding to each node of Figure 1 is shown in Figure 2 revenue change path (Copeland and Antikarov, 2001; Cheng et al., 2011):

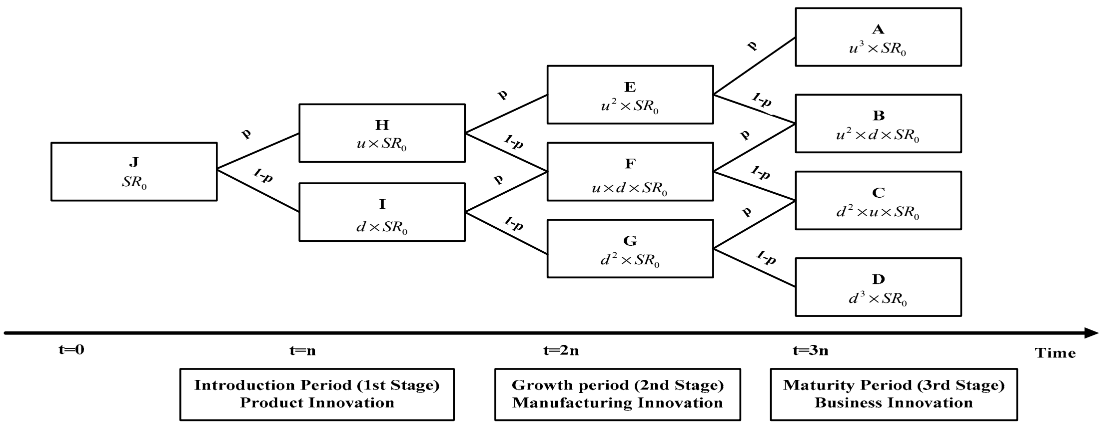

Figure 2. Revenue change path

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 July 2018 doi:10.20944/preprints201807.0563.v1

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

In Figure 2 revenue change path, this paper assumes SR_i is the revenue of i node, where $i = A, B, C, D, E, F, G, H, I, J$ and $SR_J = SR_0$ is the revenue of J node. Following the GDP variation path in the next step, where the economic growth adjusted-risk probability is p and the average growth rate of each stage is u, thus the revenue of H node is $SR_H = u \times SR_0$. In addition, the recession adjusted-risk probability is $1-p$ and the average recession rate is d; therefore, the revenue of I node is $SR_I = d \times SR_0$. Similarly, the revenue of each node is $SR_E = u^2 \times SR_0$, $SR_F = u \times d \times SR_0$, $SR_G = d^2 \times SR_0$, $SR_A = u^3 \times SR_0$, $SR_B = u^2 \times d \times SR_0$, $SR_C = u \times d^2 \times SR_0$, and $SR_D = d^3 \times SR_0$ respectively. There are two conditions, one is the corresponding GDP to each node rises, and as a result, the consumer purchase power corresponding to the GDP increases and corporate revenue also increases. Another one is as the corresponding GDP declines, consumer purchase power and corporate revenue declines.

2.2 Compound binomial options

This study utilizes the compound binomial options model (Copeland and Antikarov, 2001; Cheng et al., 2011) and the three stages of the product life cycle characteristics: introductory, growth, and maturity. For the sustainable operation of the product, each stage requires innovation cost investments: product innovation, manufacturing innovation, and business innovation. The sequence of this investment process corresponds with the characteristics of product life cycles. It is only after the investment of the first introductory stage (product innovation) is made, the option to invest in the second growth stage (manufacturing innovation) will become available, and then the last maturity stage (business innovation) will follow.

Due to the long lead time of technology innovation, this paper assumes that the investment strategy in each stage adopts the early assessment investment strategy method. That is, the investment strategy in the *E, F* and *G* nodes of the second stage is to consider whether to invest

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

in business innovation costs, or to abandon the investment project. Similarly, the investment strategy in the *H* and *I* nodes of the first stage is to consider whether to invest in manufacturing innovation, while in the stage $t=0$, the decision is to determine whether product innovation is to be continued or abandoned. Assuming C^s is the innovation cost in the stage *s*. At the stage $t=0$, the decision is to determine whether to invest in the stage $t=n$ product innovation cost. The introductory stage $t=n$ indicates whether to invest in the stage $t=2n$ growth innovation. Similarly, the growth stage $t=2n$ indicates the business innovation investment strategy for the stage $t=3n$.

This study assumes that the investment strategy in each stage adopts the early assessment investment strategy method. Therefore the consideration factors affecting whether to proceed with the next stage of investment at each revenue node of each stage include the decision point, the expected revenue of the previous stage, and the discounted present value of the revenue of the expected invested innovation cost. That is, at *E* node of the 2nd stage, the revenue at the decision point SR_E^{II} is included in the added total of the expected revenue of the 1st stage for *n* years and the discounted present value of the expected revenue of the 3rd stage after the business innovation cost is invested (Cheng et al., 2011):

$$SR_E^{II} = \frac{p \times SR_A + (1-p) \times SR_B}{e^{n*r}} + SR_E \qquad (1)$$

From Eq. (1), SR_E^{II} denotes the revenue of *E* node decision point, which is the added total of the discounted present value of *A* and *B* nodes revenues of the 3rd stage $\left(p \times SR_A + (1-p) \times SR_B\right)/e^{n*r}$, and the expected revenue SR_E. This paper constructs an investment model that incorporates the three stages of innovation strategies of new product development, and uses the early strategic decision method. That is, at the decision point of the 2nd stage, the revenue resulting from the 1st stage strategic options and the present value of the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 July 2018 doi:10.20944/preprints201807.0563.v1

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

expected revenue of the corresponding expected results of the 3rd stage are considered, which are the results of the adopted strategies at each node of the 2nd stage.

Similarly, SR_F^{II} denotes the revenue of F node decision point as shown in Eq. (2) (Cheng et al., 2011):

$$SR_F^{II} = \frac{p \times SR_B + (1-p) \times SR_C}{e^{n*r}} + SR_F \tag{2}$$

Then, SR_G^{II} denotes the revenue of G node decision point as shown in Eq. (3) (Cheng et al., 2011):

$$SR_G^{II} = \frac{p \times SR_C + (1-p) \times SR_D}{e^{n*r}} + SR_G \tag{3}$$

Then, at H node in the 1st stage, the consideration factors, when facing the decision of investing in the manufacturing innovation cost, include the discounted present value of the expected revenues of E and F nodes of the 2nd stage $\left(p \times SR_E^{II} + (1-p) \times SR_F^{II}\right)/e^{n*r}$, and the expected revenue SR_H (Cheng et al., 2011):

$$SR_H^{I} = \frac{p \times SR_E^{II} + (1-p) \times SR_F^{II}}{e^{n*r}} + SR_H \tag{4}$$

Similarly, SR_I^{I} denotes the revenue of I node decision point as shown in Eq. (5) (Cheng et al., 2011):

$$SR_I^{I} = \frac{p \times SR_F^{II} + (1-p) \times SR_G^{II}}{e^{n*r}} + SR_I \tag{5}$$

The revenue of J node decision point is denoted as SR_J^0 as shown in Eq. (6) (Cheng et al, 2011):

$$SR_J^{0} = \frac{p \times SR_H^{I} + (1-p) \times SR_I^{I}}{e^{n*r}} \tag{6}$$

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

This paper continues to calculate the equity values of nodes *E, F, G, H, I, J*. Assuming NP_i^s is the equity value of *i* node of *s* stage, the rule of the decision is that when the equity value is greater than 0, i.e. $NP_i^s > 0$, the option is to invest; if the equity value is smaller than 0, i.e. $NP_i^s < 0$, the option is to abandon the investment or to wait for the next appropriate investment opportunities.

The option of whether to invest in the business innovation cost is at *E* node. Its equity value NP_E^{II} equals the decision point revenue of the 2nd stage SR_E^{II} minus the business innovation cost C^{III} invested during the 2nd stage. When the value is greater than 0, the plan of investing in the business innovation cost will be implemented; otherwise, the choice will be to abandon the plan or to wait for the next investment opportunity when the equity value equals 0. The *E* node option of whether to invest in the business innovation cost and its equity value are shown in Eq. (7):

$$NP_E^{II} = MAX\left[SR_E^{II} - C^{III}, 0\right] \tag{7}$$

Additionally, the equity value of *F* node NP_F^{II} equals the decision point revenue of the 2nd stage SR_F^{II} minus the business innovation cost C^{III} invested in the 2nd stage. When the value is greater than 0, i.e. $NP_E^{II} > 0$, the option will be to invest in the business innovation cost; otherwise, the option will be to defer the investment. The *F* node option of whether to invest in the business innovation cost and the equity value are shown in Eq. (8):

$$NP_F^{II} = MAX\left[SR_F^{II} - C^{III}, 0\right] \tag{8}$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 July 2018 doi:10.20944/preprints201807.0563.v1
Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

Likewise, G node equity value NP_G^{II} equals the decision point revenue of the 2nd stage SR_G^{II} minus the business innovation cost C^{III} invested in the 2nd stage. When the value is greater than 0, i.e. $NP_G^{II} > 0$, the option will be to invest in the business innovation cost; otherwise, the option will be to defer the investment. The G node option of whether to invest in the business innovation cost and the equity value are shown in Eq. (9):

$$NP_G^{II} = MAX\left[SR_G^{II} - C^{III}, 0\right] \tag{9}$$

The equity value of H node NP_H^I must include the results of the decision point revenue of the 1st stage SR_H^I minus the invested manufacturing innovation cost C^{II} of the 1st stage. It means that when $SR_H^I - C^{II}$ is greater than 0, it is worth proceeding with the investment. Because the investment decision is correlated to the decision of business innovation investment of the 3rd stage, this consideration must also include the discounted present value of the expected equity return of E and F nodes of the 2nd stage $\frac{p \times NP_E^{II} + (1-p) \times NP_F^{II}}{e^{n*r}}$. If the value is greater than 0, it is one of the consideration factors in the manufacturing innovation cost investment decision, that is, when $NP_H^I > 0$, investing in the manufacturing innovation cost will be considered. But if $NP_H^I = 0$, the option will be to abandon the investment in the manufacturing innovation cost and wait for another opportunity as shown in Eq. (10):

$$NP_H^I = MAX\left[SR_H^I - C^{II}, \frac{p \times NP_E^{II} + (1-p) \times NP_F^{II}}{e^{n*r}}, 0\right] \tag{10}$$

Likewise, the equity value of I node NP_I^I must include the results of the decision point revenue of the 1st stage SR_I^I minus the invested manufacturing innovation cost C^{II} of the 1st

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

stage. It means that when $SR_I^I - C^{II}$ is greater than 0, it is worth proceeding with the investment. Because the investment decision is correlated to the decision of business innovation investment of the 3rd stage, this consideration must also include the expected equity values of *F* and *G* nodes of the 2nd stage $\frac{p \times NP_F^{II} + (1-p) \times NP_G^{II}}{e^{n*r}}$. If the value is greater than 0, it is one of the consideration factors in the manufacturing innovation cost investment decision, that is, when $NP_I^I > 0$, investing in the manufacturing innovation cost will be considered. But if $NP_I^I = 0$, the option will be to abandon the investment in the manufacturing innovation cost and wait for another opportunity as shown in Eq. (11):

$$NP_I^I = MAX\left[SR_I^I - C^{II}, \frac{p \times NP_F^{II} + (1-p) \times NP_G^{II}}{e^{n*r}}, 0 \right] \tag{11}$$

The equity value of *J* node NP_J^0 includes the results of expected revenue after the product innovation cost is invested SR_J^0 minus the results of whether to invest in the product innovation cost C^I in stage 0, i.e. $SR_J^0 - C^I$. In addition, this calculation must also include the expected equity value of *H* and *I* nodes of the 1st stage $\frac{p \times NP_H^I + (1-p) \times NP_I^I}{e^{n*r}}$ because if the innovation cost is not invested at *J* node, neither manufacturing innovation nor business innovation is possible. Therefore, the consideration factor in stage 0 includes the decision to invest the profit in innovation costs. If losses are incurred in stage 0, the equity value of manufacturing innovation of the 1st stage is still one of the consideration factors. That is, when $NP_J^0 > 0$, investing in the product innovation cost will be considered. But when $NP_J^0 = 0$, the option is to abandon the investment or to defer to the next investment opportunity as shown in Eq. (12):

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

$$NP_J^0 = MAX\left[SR_J^0 - C^I, \frac{p \times NP_H^I + (1-p) \times NP_I^I}{e^{n^*r}}, 0\right] \tag{12}$$

The equity value NP_i^s of nodes *E, F, G, H, I, J* and the equity values of binomial options are shown in Fig. 3:

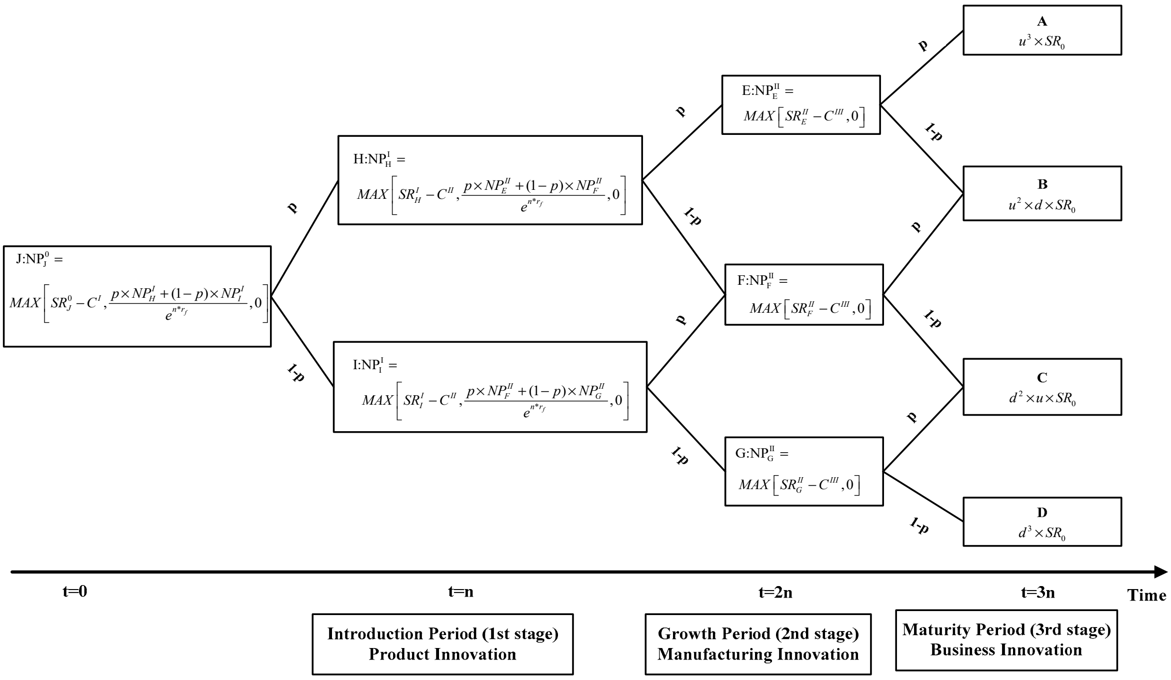

Figure 3. Equity values of binomial options

Fig. 3 is the equity values of binomial options. This model employs a compound binomial options approach, which is more flexible in strategic thinking than other approach to construct an innovation investment strategy, which is product life cycle specific. Its strategic principle is that when the equity value is greater than 0, i.e. $NP_i^s > 0$, the option is to proceed with the investment; if the value equals 0, i.e. $NP_i^s = 0$, the option is to abandon the investment or to defer to the next appropriate investment opportunity. This model serves as a reference for corporate decision-making in product investment strategies. Section 3 below uses a firm case study, where One-Time Password's investment is studied and simulation analysis is performed, providing a basis for managerial reference when considering the product innovation investment.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 July 2018 doi:10.20944/preprints201807.0563.v1

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

3. Numerical examples

By using the constructed model in section 2 as a base, this paper analyzes a case study of a firm with the product, One-Time Password, in an uncertain investment environment scenario, and assesses the innovation cost investment worthiness of each stage.

Based on the historical GDP data from 1995 through 2017, this paper estimates the future GDP changes, and assesses the changes in the future consumer purchasing power, which in turn affects the revenue. That is, the changes in the future revenue are dependent on the GDP change model. This paper assumes when $t = 0$ of the case firm, the estimated One-Time Password's revenue is NT\$18.00 (million), i.e. J node revenue is $SR_J = 18.00$ (million). Its relevant parameter assumptions are shown in table 1:

Table 1. Parameter assumptions

Parameter	Definition	Value	Parameter	Definition	Value
u	GDP average growth rate in every five years	1.21	d	GDP average decline rate in every five years	0.83
n	A period of five years	5.00	r	Risk-adjusted discounted Rate	0.68%
p	GDP risk-adjusted growth probability	0.54	$1-p$	GDP risk-adjusted recession probability	0.46
C^{I}	Product innovation cost	20.00 (million)	C^{II}	Manufacturing innovation cost	20.00 (million)
C^{III}	Business innovation cost	50.00 (million)	SR_J	Estimated one time passwords stage 0 revenue	18.00 (million)

After incorporating values to Figure 2 revenue change path, each node's revenue is shown in Figure 4 revenue (SR_i) change path:

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

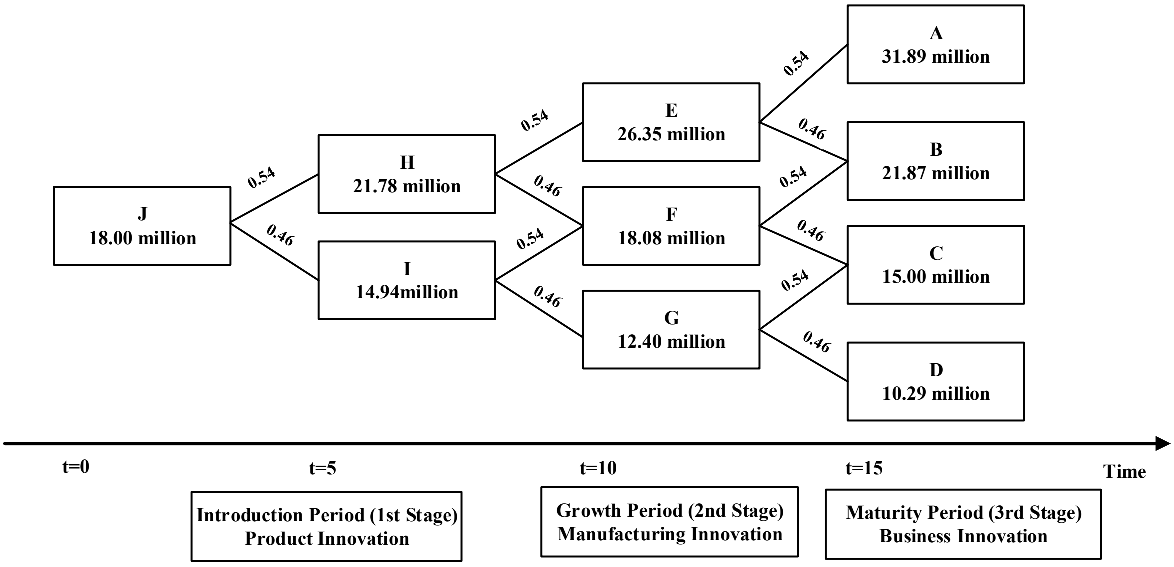

Figure 4. Revenue (SR_i) changes path ($r = 0.68\%$)

This paper assumes that the investment strategy for each stage adopts the early assessment investment strategy method. Therefore, the consideration factors affecting whether to proceed with the next phase of investment or to abandon the project at each revenue node of each stage include the decision point, the expected revenue of the previous stage, and the discounted present value of the revenue of the next stage after the innovation cost is invested. Each decision point revenue SR_i^s is shown in Figure 5:

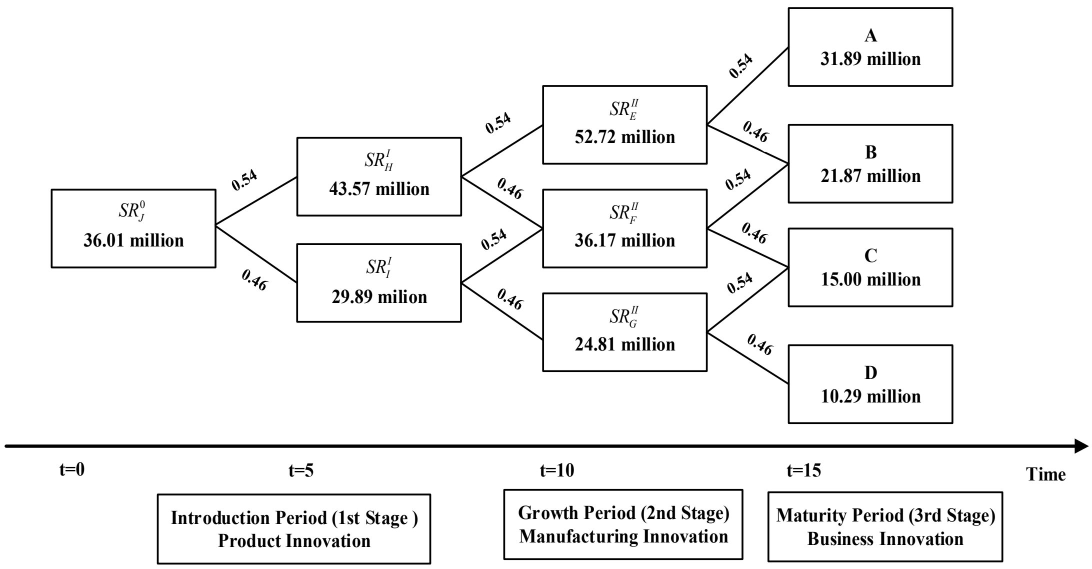

Figure5. Revenue SR_i^s value of each node of compound binomial options ($r = 0.68\%$)

This paper continues to calculate the equity value of *E, F, G, H, I* and *J* nodes. NP_i^s denotes the equity value of *i* node of *t* period. Its equity value of each node of compound binomial options is shown in Figure 6:

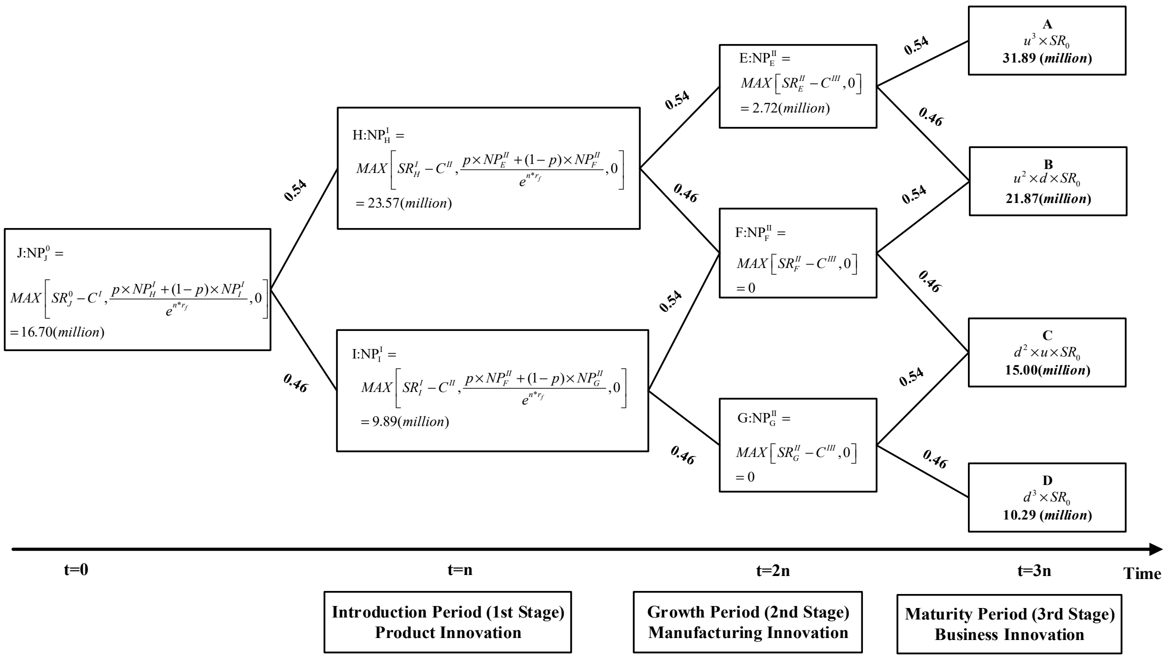

Figure 6. The compound binomial equity values ($r = 0.68\%$)

Figure 6 shows that C^{III}=50 million dollars of business innovation cost is invested at *E* node, which means the resulting value derived from the expected revenue of the 2nd stage SR_E^{II} minus the invested business innovation cost of the 2nd stage C^{III} is greater than 0 so it is worth investing. But the *F* and *G* nodes of the 2nd stage, the respective resulting value derived from SR_F^{II} and SR_G^{II} minus the invested business innovation cost of the 2nd stage C^{III} is less than 0 so the option is to wait and not to proceed with the investment. As both equity values of *H* and *I* nodes NP_H^I and NP_I^I derived from the expected sales revenue of the 1st stage SR_H^I and SR_I^I minus the invested manufacturing innovation cost of the 1st stage $C^{II} = 20$ million are greater than 0 so the option is to proceed with the investment. At *J* node, the product innovation cost is invested and the expected five year sales revenue minus the considered

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

product innovation cost $C^I = 20$ million dollars is 16.01 million dollars that is greater than 0 so it is worth investing. At the same time, the investment plan considers three stages, the product innovation in the first stage of the introduction period, the manufacturing innovation in the second stage, and the business innovation in the third stage. Therefore, the decision point must also consider the expected equity of the first stage node H and I node $\frac{p \times NP_H^I + (1-p) \times NP_I^I}{e^{n*r}} = 16.70$ million dollars. So, take a larger value according to Eq.(12) $NP_J^0 = 16.70$ million dollars. Its compound options values are shown in Fig. 7:

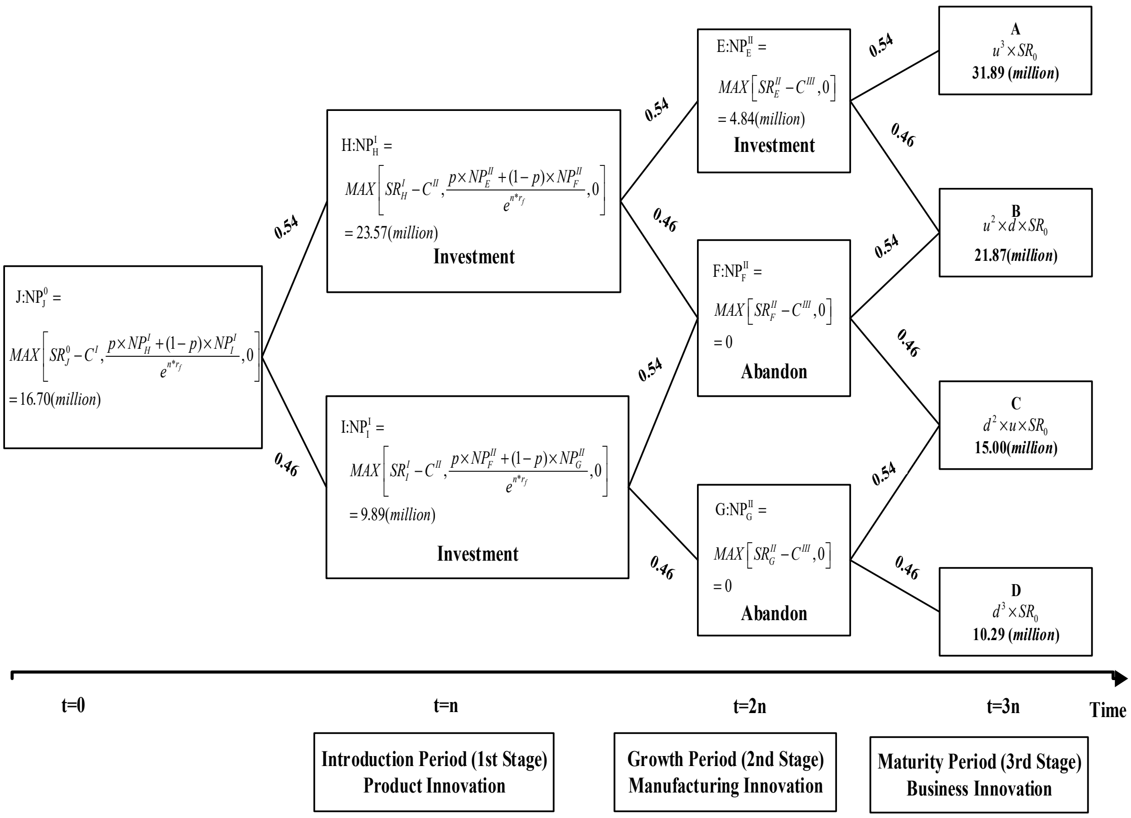

Figure 7. Compound options decision-making tree ($r = 0.68\%$)

This paper utilizes a more flexible strategic thinking method, the compound binomial options, to construct the product life cycle innovation investment strategy model, and divides the decision-making process into three phases. It is only after the investment of the 1st stage introductory period (product innovation) is made, the option to invest in the second stage

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 July 2018 doi:10.20944/preprints201807.0563.v1

Peer-reviewed version available at Risks 2018, 6, 98; doi:10.3390/risks6030098

growth period (manufacturing innovation) will become available, and then the last stage maturity period (business innovation) will follow.

After a numerical analysis, the results show the equity value of the investment is greater than 0, which means it is worth investing for the case firm. This result is offered to the manager of the case firm as a reference for the product innovation investment.

Based on the changes of risk-adjusted discounted rate r, which affects the revenue growth path risk-adjusted probability p and the decline path risk-adjusted probability $1-p$, this paper analyzes the changes of expected revenue of binomial options and their influence on equity values. The changes are shown in Table 2:

Table 2. The influence of the risk-adjusted discounted rate *r* on equity values

Risk-adjusted discount rate (r)	Revenue growth path risk-adjusted probability (p)	Revenue decline path risk-adjusted probability (1-p)	Equity value (NP_i^s)
0.48%	0.52	0.48	16.38(million)
0.68%	0.54	0.46	16.70(million)
1.08%	0.60	0.40	17.09(million)
1.48%	0.65	0.35	17.18(million)
1.68%	0.68	0.32	17.68(million)

As shown in Table 2, when the risk-adjusted discounted rate r rises, the revenue growth path risk-adjusted probability p also rises, which means the probability of future economic growth is higher. When the revenue decline path risk-adjusted probability $1-p$ is lower, the future economic recession probability is lower and the equity value of the case firm's project - one time passwords' technology innovation investment is higher. Because when the risk-adjusted discounted rate r rises, the case firm's investment risk in the project increases;

Peer-reviewed version available at *Risks* **2018**, *6*, 98; doi:10.3390/risks6030098

therefore, a higher equity value must be present in order to attract the case firm's investment interest.

Then, we will change the average growth rate of GDP every five years *u*. Linkage affects the average annual decline rate of GDP every five years *d*. And for the impact of the rising profit path risk adjustment probability p and the decline path risk adjustment probability $1-p$ change situation. Analysis of changes in expected returns of binomial options and their impact on equity values. The changes are shown in Table 3:

Table 3. The influence of the GDP average growth rate in every five years *u* on equity values

GDP average growth rate in every five years (u)	GDP average decline rate in every five years(d)	Revenue growth path risk-adjusted probability (*p*)	Revenue decline path risk-adjusted probability (*1-p*)	Equity value (NP_i^s)
1.10	0.91	0.66	0.34	16.71(million)
1.21	0.83	0.54	0.46	16.70(million)
1.30	0.77	0.50	0.50	16.68(million)
1.40	0.71	0.47	0.53	16.65(million)
1.50	0.67	0.44	0.56	16.70(million)
1.60	0.63	0.42	0.58	16.82(million)

As shown in Table 3, If the average GDP growth rate u rises, the revenue growth path risk-adjusted probability p will be lower. Due to the economic cycle, the probability of prosperity will decline; and revenue decline path risk-adjusted probability $1-p$ will increase. That is, the probability of future economic recession is gradually rising. The case firm's project - the equity value of the one-time passwords' technology innovation investment case, In addition to considering the growth rate of consumption (the average GDP growth rate u), we must also consider t the revenue growth path risk-adjusted probability p or revenue decline path risk-adjusted probability $1-p$. When the average GDP growth rate *u*=1.10~1.40, its equity value gradually declines. And when the average GDP growth rate *u*=1.40~1.60, its equity value is gradually growing. And at the same time of analysis, when u=1.10, in the third stage of business innovation, the E, F, G nodes have the option value of 0, $NP_E^{II}=0$, $NP_F^{II}=0$, $NP_G^{II}=0$. Therefore, when u=1.10, you should choose to abandon the investment in business innovation.

4. Conclusions

This paper utilizes a more flexible management method, the compound binomial options, to construct an investment strategy model. This paper takes into account the circumstance that confronts the policy maker: the changes of external environment, that is, the uncertainty of GDP growth, which affects consumer purchasing power, which in turn affects business revenues. This paper divides the product life cycle based on its characteristics into three stages: introductory, growth, and maturity, and explores the decision making process of whether to invest in technology innovation: product innovation in the introductory period, manufacturing innovation in the growth period, and business innovation in the maturity period. The strategic principle of this model is that only after the investment of the 1st stage introductory period (product innovation) is made, the option to invest in the next stage will become available; after entering the 2nd stage growth period (manufacturing innovation), the investment of the 3rd stage maturity period (business innovation) will be considered. This paper uses this model to assess the optimal investment strategy of each stage and the project values as well as options premiums of the decision-making points.

This paper applies this model to the technology innovation decision-making process of the case firm's product, one time passwords. Based on the product's characteristics, this paper divides its life cycle into three stages: product innovation, manufacturing innovation, and business innovation. Various stages beget various scenarios that require various policy models. After applying a numerical analysis, the result shows the equity value of the investment is greater than 0. Thus this paper recommends the case firm to invest in one time passwords innovation project. This result differs from the net present value (NPV) method, originally used by the firm, which assumes a static investment environment and only considers continuous economic growth. The assessment is perhaps unduly optimistic. Whereas, this paper constructs an investment model that considers the uncertainty of the investment environment and takes into account future economic growth and decline. This paper also concludes that when the risk-adjusted discounted rate increases, the risk of the investment market increases, and that the equity value must also be higher in order to attract the case firm's investment interest. This result is offered to the manager of the case firm as a reference for the product innovation investment.

This model is designed specifically for the technology products with short life cycles, which require constant technology innovation investment to extend product life cycles in an uncertain market. The model utilizes the compound binomial options assessment model, which has management flexibility and includes an investment that is decision relevant and has options to choose in each phase. Using this model to assess the innovation investment issues of each phase of the product life cycle offers more flexibility in decision-making than other trend forecasting standards, and the results can be used as a reference for business policy makers in extending product life cycles.

Acknowledgments

The authors would like to thank the Ministry of Science and Technology of the Republic of China, Taiwan for financially supporting this research under Grant No. MOST 104-2410-H-259-035-MY3.

References

Ball Daniel R., Abhijit Deshmukh, and Nikunj Kapadia. 2015. An options-based approach to coordinating distributed decision systems. *European Journal of Operational Research* 240(3): 706-717.

Copeland, Tom, and Antikarov Vladimir. 2001. Real Options: A Practitioner's Guide. New York: Texere Press.

Cassimon, Danny, Peter-Jan Engelen, and Vilimir Yordanov. 2011. Compound real option valuation with phase-specific volatility: a multi-phase mobile payments case study. *Technovation* 31(5-6): 240-255.

Cheng, Ching-Tsung, Shang-Lien Lo, and Tyrone T. Lin.2011. Applying real options analysis to assess cleaner energy development strategies. *Energy Policy* 39(10): 5929-5938.

Daming, You, Yang Xiaohui, Desheng Dash Wu, and Chen Guofan. 2014. Option game with Poisson Jump Process in company radical technological innovation. *Technological Forecasting and Social Change* 81: 341-350.

De Kluyver, Cornelis A. 1977. Innovation and industrial product life cycles. *California Management Review* 20(1): 21-33.

Dixit, Avinash K., and Robert S. Pindyck. 1994. Investment under Uncertainty. Princeton: Princeton University Press.

Detemple, Jerome, and Yerkin Kitapbayev. 2018. Optimal Investment under Cost Uncertainty *Risks* 6(1), 5; https://doi.org/10.3390/risks6010005

Koosha, Hamidreza, and Amirb Albadvi. 2015. Customer lifetime valuation using real options analysis. *Journal of Marketing Analytics* 3(3): 122-134.

Lin, Tyrone T. 2010. Assessment of decision-making regarding market entry/exit for technology innovation. *Quality & Quantity* 44(3): 447-457.

Lo Nigro, Giovanna, Gianluca Enea, and Azzurra Morreale. 2014. Open innovation: a real option to restore value to the biopharmaceutical R&D. *International Journal of Production Economics*, 149, 183-193.

Lin, Tyrone T. 2009. Applying the maximum NPV rule with discounted/growth factors to a flexible production scale model. *European Journal of Operational Research* 196(2): 628-634.

Lin, Tyrone T, and Shio-Ling Huang. 2011. Application of the modified Tobin's q to an uncertain energy-saving project with the real options concept. *Energy Policy* 39(1): 408-420.

Lee, Jen Chieh, and Tyrone T. Lin. 2018. A three-stage real options model on fire risk management decision-making under the fire loss frequency uncertainty. *Asia Pacific Management Review* 23(1): 37-44.

Liu, Yu-hong, I-Ming Jiang, and Li-chun Chen. 2017. Valuation of n-fold compound barrier options with stochastic interest rates. *Asia Pacific Management Review* 1-17.

Myers, Stewart C. 1977. Determinants of corporate borrowing. J*ournal of Financial Economics* 5(2): 147-175.

Peer-reviewed version available at *Risks* **2018**, *6*, 98; doi:10.3390/risks6030098

Morozko, Natalia, Nina Morozko, and Valentina Didenko. 2018. Rationale for the development strategy of small business organizations using the real options method. *Academy of Strategic Management Journal* 17(2): 1-11.

Morreale, Azzurra, Serena Robba, Giovanna Lo Nigroa, and Paolo Roma. 2017. A real options game of alliance timing decisions in biopharmaceutical research and development. *European Journal of Operational Research* 261(3): 1189-1202.

Verdu, Antonio J., Ignacio Tamayo, and Antonia Ruiz-Moreno. 2012. The moderating effect of environmental uncertainty on the relationship between real options and technological innovation in high-tech firms. *Technovation* 32(9-10): 579-590.

Wang, Juite, and Chung-Yu Yang. 2012. Flexibility planning for managing R&D projects under risk. *International Journal of Production Economics* 135(2): 823-831.