A Two-Stage Stochastic Programming Model for Technological Knowledge Acquisition Based On Game Theory

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Firms outperforming competitors often get their success through innovation and new technological knowledge acquisition. This study offers a Three-Stage decision-making model for acquiring new technological knowledge and the optimal time to invest. In the first Stage, two competing firms decide to invest in a new technological knowledge without knowing its level. In the next stage, firms will develop and integrate it with their knowledge. Due to the uncertainty of new technological knowledge, a stochastic programming model is used to determine the optimal acquisition time. This model identifies the leader and follower by considering advantages such as branding and high market share as well as disadvantages such as high cost of uncertainty. Finally, we used Cournot and Stackelberg game to determine the winner in the market. The proposed model can be used as a decision-making tool to help organizations, in uncertainty, invest as leaders in acquiring new technological knowledge and entering the market, or wait until things are clear. The results of stochastic programing and game theory model show that the level of knowledge of firms at the time of production, knowledge absorption coefficient, and constant demand coefficient will have a special effect on determining the winner in the market.

Keywords: Technological Knowledge Investment; Knowledge Acquisition; Knowledge Development; Game Theory; First Mover Advantage;

1. Introduction

Companies use their existing knowledge to develop the product and present it to the market. This knowledge may come from the educational background of the employees who work on the product development project, work experience, performance evaluations, and past experiences of similar research and projects. These sources of knowledge are helpful but it is not enough to reduce the price of products or increase their quality and maintain a competitive advantage in the market. Technological knowledge is a new innovation or technology that reduces production costs [1].

New knowledge adoption, or deciding to acquire the best knowledge at the best time, in a competitive environment and uncertainty, has become a key issue in companies' profitability. Acquiring this new knowledge is a strategic decision that has faced many challenges for organizations. The new technological knowledge is associated with uncertainty, and until be fully captured by firms, its actual level will not be revealed [2]. In addition, not all of this technological knowledge is transferred to the company, and anyone who has more available knowledge will absorb more of it. On the other, a quick acquisition of it will lead to a first-mover advantage, including brand loyalty, technological leadership, and the preemption in acquiring scarce assets [3-6]. However, acquiring new technological knowledge often involves significant spending on research and development, and the first one who absorbs it, bears the main burden of these costs [7].

Researchers in recent years have used various methods to model knowledge acquisition problem, including system dynamics, impact analysis, scenario analysis, risk assessment, and decision analysis [8-16]. But these models do not take into account important parameters such as competition; Game theory is one of the tools that can model the conflict of interest in new knowledge adoption by considering the competition between firms [17-25].

In addition to the competition, uncertainty and the technical level of new knowledge, as well as the level of knowledge of firms, should be considered in deciding to acquire it. This work focuses on the optimal timing of the adoption of a cost-reducing technological knowledge by two competing firms. We discuss profit-maximizing behavior in three stages. We assume that the new technological knowledge is uncertain and its value will be determined when it is acquired by the firms. Two competing firms decide to acquire new knowledge in the face of uncertainty, and the firm that acquires it sooner at a higher cost will be able to enter the market as a leader. We assume that the production cost will be inversely related to the total knowledge acquired and the existing knowledge of the firm. Finally, according to the cost of production for each firm, they enter a game to determine the amount of product in the market and the winner will be determined. To model these concepts, a two-stage stochastic model is developed for deciding on the time of new technological knowledge acquisition, based on which, the product amount of each firm is determined by a Cournot or Stackelberg game.

New knowledge adoption is a strategic decision that involves a variety of dimensions. This decision is based on four levels: new knowledge, firm, competitive environment and the market. At the level of new knowledge, its fitness to the firm's capabilities is very important and the need for knowledge assessment is based on external and internal factors. At the firm level, the initial knowledge of the firm has a great impact on the success of knowledge acquisition and product development in the market. Competition and the time of new knowledge adoption and methods of acquiring it are the main factors of the competitive environment. Ultimately, the uncertainty that exists in new knowledge, the competitive environment, and the market will affect the success or failure of the acquisition of new knowledge. To this end, many models for optimal decision making of the new knowledge acquisition by researchers to consider the above factors have been used but most of them are suitable for covering one or more of the above factors. This study unveils a model for new knowledge acquisition decision making that uses two-stage stochastic programming and game theory to solve investment problem in the uncertainty environment and if utilized properly, can be utilized as a decision support tool for firms to find the optimal timing of the adoption of a cost-reducing technological knowledge. This tool will help managers of organizations to choose the best time to invest and make the most profit in the market, given the uncertainty of new knowledge as well as the existing level of knowledge of the firm.

The remainder of the paper is organized as follows. Section 2 reviews the literature on technological knowledge adoption. Section 3 discusses the model framework. Section 4 offers some experimental results and managerial insights. The paper is concluded in Section 5 by outlining the major insights and future research avenues.

2. Literature Review

Acquiring new technological knowledge has profit and risk, which makes it important in competitive markets [26, 27]. So, in recent years, researchers have paid much attention to the effect of the new technological knowledge acquisition on market structure and competition between firms.

2.1. *Strategic Decision Making on Technological Knowledge Adoption*

Nowadays, absorbing a new knowledge is considered as a strategic decision issue for companies. This strategic decision-making consists of three dimensions: 1) Knowledge selection, 2) timing of Knowledge Development (KD) and introduction and 3) knowledge acquisition mode. These three dimensions' influence each other. The knowledge strategy elements are shown in Figure **1** [28].

2.2. *Technological Knowledge Selection*

The selection of technologies is a key step in the overall technology-development process of the firm. In recent years, much attention has been paid to establishing criteria for evaluating different knowledge and selecting the best one for investment [26, 29, 30]. The factors for assessing the new knowledge can be categorized internally and externally. These factors include the cost of adoption, production capacity, market status and ... as shown in the Table **1**.

2.3. *Timing of Knowledge Adoption*

One of the main dimensions of decision-making for investing in new knowledge is adoption time. Studies show that leaders are earning more incomes than their rivals, but also face higher costs, which in the long time lead to fewer profits [7]. Table **2** shows the advantages of being first or second mover.

2.4. *Technological Knowledge Acquisition Model*

The third dimension of a technology strategy is the method of acquiring knowledge, which means that the development of knowledge through internal development, collaboration with other firms or institutions, or the purchasing knowledge. In the literature of knowledge sourcing, there are several ways to acquire a knowledge, each with its own characteristics [31]. Table **3** shows studies of different types of knowledge acquisition methods.

In addition to timing, selection, and acquisition mode, a compehensive model to develope for new knowledge adoption should consider the market structure, the competition, uncertainty and the knowledge level of firms

2.5. *Customer Segments of Technology Adoption*

When a new product is introduced to the market, not everyone will select it at the same time. Studies have shown users of a new product can be divided into the following groups (Figure 2):

- Innovators: The group of people who look for innovation
- Early adopters: the group of people who use a new product or technology before it becomes widely known or used.
- Early majority: The group of people who purchase new products after a much smaller population of innovators and early adopters has done so.
- Late majority: people in this category will adopt an innovation after the average member of the society.
- Laggards: refers to the last large group of people to adopt a new product or technology.For a new product to take off, the first two groups are obviously the most important ones [32].

2.6. *Knowledge Adoption Methods*

Since new knowledge adoption is an investment project, most of these projects following three characteristics: uncertainty, competition and knowledge level of firms. The knowledge adoption (almost) always has to deal with uncertainty. For most investments the future revenues are stochastic, due to uncertainties in, e.g., the firm's market shares and the market price. It is also possible that the investment cost is uncertain, which is the case in many infrastructure projects. On the other competition is an effective factor in new knowledge adoption. studies show that competition limits the ability of firms to appropriate the benefits of new technology adoption [33]. Most knowledge acquisition assessment models consider “intangible benefits” (i.e., benefits like customer satisfaction, improved employee motivation, etc.), such as multiobjective, multi-criteria methods, value analysis, critical success factors, methods for risk, real option, portfolio approach, and the Delphi method [34]. Other studies on technological knowledge investment methodologies seek to just define a combination of quantitative and qualitative methods. In the Table **4**, the most important methods used in the modeling of new knowledge investment are discussed.

New knowledge adoption is a strategic decision that involves a variety of dimensions. This decision is based on four levels: new knowledge, firm, competitive environment and the market. At the level of new knowledge, its fitness to the firm's capabilities is very important and the need for knowledge assessment is based on external and internal factors. At the firm level, the initial knowledge of the firm has a great impact on the success of knowledge acquisition and product development in the market. Competition and the time of new knowledge adoption and methods of acquiring it are the main factors of the competitive environment. Ultimately, the uncertainty that exists in new knowledge, the competitive environment, and the market will affect the success or failure of the acquisition of new knowledge. To this end, many models for optimal decision making of the new knowledge acquisition by researchers to consider the above factors have been used that can be referred to financial and non-financial methods.

Examining the various models mentioned in this article shows that most methods are suitable for covering one or more of the above factors. One of the ways in which it can be used to cover all six critical factors in the success or failure of knowledge acquisition is the game theory. As shown in Table 4, many researchers have used this tool to model selection, timing and method of acquiring knowledge. The theory of the game uses mathematical models to analyze the methods of co-operation or competition of rational and intelligent beings. This study unveils a model for new knowledge acquisition decision making that uses two-stage stochastic programming and game theory to solve investment problem in the uncertainty environment.

3. Research contribution

Base on the proceeding discussion, this study unveils a model for new knowledge acquisition decision making that uses two-stage stochastic programming and game theory to solve investment problem in the uncertainty environment. Finally, significant novelties and contributions that separate this research from pertinent literature are as follows:

3.1. *Knowledge flow*

In this research, to increase the level of firms' technological knowledge, two ways are considered: technological Knowledge Transfer (KT) and development. The knowledge flow in this article includes:

- **The level of new knowledge** :In the first stage of the New Product Development (NPD) project, new technological knowledge choice raised for technological knowledge transfer.
- **Initial level of knowledge:** The initial technological knowledge level includes education records, work experience, and evaluation of employees' performance in the NPD project. In the first stage, the technological knowledge level of each firm changes due to the technological KT.
- **Knowledge Absorption:** Absorptive capacity is the ability to learn from external technological knowledge through processes of technological knowledge identification, assimilation, and exploitation.
- **KD:** It includes processes of external technological knowledge procurement, creation of specific technological knowledge resources like research and development departments, and formation of personal/ technical technological knowledge networks.

3.2. *Competition*

Two competing firms will produce their products in a duopoly competitive market, with investing in new technological knowledge that is uncertain. Competition between two firms starts with acquiring knowledge and will continue until the product is sold in the market. The competition in this work includes:

- **Leader or follower:** In the proposed model, the firm that acquires new knowledge sooner at a higher cost will be able to enter the market as a leader.
- **switching customers:** In the proposed model, one of the competitive advantages that is considered is based on customers who compare the level of knowledge used in the product and choose a higher quality product.
- **marginal cost:** In the proposed model, the two firms are deciding on gaining new technological knowledge that will reduce their costs. The range of the reduction in marginal cost depends on the quality of the new

technological knowledge. The higher technological knowledge level and the greater absorption coefficient will lead to lower marginal cost in producing.

3.3. *Knowledge acquisition time*

One of the main criteria in acquiring new knowledge is time, which in this article includes the following:

- **knowledge acquisition time:** In the proposed model, the cost of uncertainty is considered for acquiring knowledge earlier, and the firm that acquires knowledge later can use the opportunity to learn from the competitor.
- **Innovators and early adopters market share:** Innovators and early adopters, which constitute 16 percent of the total market demand, are waiting for a new product to buy, and the first-mover can make use of this advantage.

3.4. *Uncertainty*

Two competing firms decide to acquire new knowledge in the uncertainty condition. The new technological knowledge has two-level of quality and firms cannot differentiate between them until they earn it.

3.5. *Model*

In this study, a two-stage stochastic model is developed for deciding on the time of new technological knowledge acquisition, based on which, the product amount of each firm is determined by a Cournot or Stackelberg game. In the proposed model, due to the uncertainty environment, a robust optimization approach is applied. Using nominal data, the game theory-based mixed-integer problem under deterministic and robust conditions has been coded by the Benders optimization algorithm in GAMS software.

4. Model framework.

Two competing firms will produce their products in a duopoly competitive market, with investing in new technological knowledge that is uncertain. The study includes the following assumptions:

- The competition is non-cooperative and symmetric.
- New technological knowledge is from the outside and has uncertainty.
- Two scenarios are considered for new technological knowledge: high or low quality.
- The acquisition of new technological knowledge reduces production cost.
- Demand is definitive.

The Table 5 represents model indexes, variables and parameters. The decision making takes place in three stages:

- **Stage 1: Acquiring new technological knowledge**. The first stage consists of two periods $(j \in \{1,2\})$ in which firms will invest to buy the new technological knowledge without knowing its level. Any firm which gains new technological knowledge will enter the market sooner. It is worth noting that if the process of gaining technological knowledge is sequential, the second-mover will be less cost-driven because of learning this process but the first-mover will faster reach the technological knowledge of the production and will make more profit from customer demand (innovators and early adopters).
- **Stage 2: Technological KD and integration** At the end of the first stage, firms will develop and integrate new technological knowledge with their first technological knowledge. The cost of developing technological knowledge at this stage depends on the new technological knowledge level and the first technological knowledge of the firm: if the new technological knowledge level is high, firms incur less expense for developing and integrating technological knowledge to produce the product.
- **Stage 3: Determining Market Structure.** As discussed in the first stage, if the acquisition is sequential, the share of 16% of customers is owned by the first mover. But to determine the share for

covering the remaining demand, it is necessary to create a Cournot or Stackelberg game. Figure 3 shows the model framework.

4.1. *Technological knowledge levels.*

In this research, to increase the level of firms' technological knowledge, two ways are considered: technological KT and development. The variable K_{ij} represents the level of technological knowledge used in the NPD project by firm *i* at time *j*, where $i \in \{1,2\}, j \in \{0,1,2\}$. In the first stage, the technological knowledge level of each firm changes due to the technological KT.

In the first stage of the NPD project, new technological knowledge choice raised for KT. The new technological knowledge (K_{new}) has two-level of quality and firms cannot differentiate between them. Various scenarios for new technological knowledge include Eq. (1) :

$$K_{new} = K_{new}^s ; s = 1,2 \qquad (1)$$

where S stands for the scenarios and α is the probability of a low-quality technological knowledge scenario $(p\{s=1\}=\alpha)$ and *1-α* is the probability of a high-quality technological knowledge scenario $(p\{s=2\}=1-\alpha)$.We consider the KT_i as a KT driven change in the technological knowledge level of firm *i* in the first stage (Eq. (2)).

$$K_{i1} = K_{i0} + KT_i ; i = 1,2 \qquad (2)$$

With the increase in absorption capacity, firms benefit more from KT. The absorption capacity of each firm is considered as β_i. Therefore, the amount of technological knowledge at the end of the first period is as Eq. (3).

$$K_{i1}^s = K_{i0} + \beta_i K_{new} = \begin{cases} K_{i0}+\beta_i K_{new}^1, p=\alpha \\ K_{i0}+\beta_i K_{new}^2, p=1-\alpha \end{cases} ; i = 1,2 \qquad (3)$$

The second way to increase the level of technological knowledge is to develop existing technological knowledge (KD), which occurs in the second period. Let KD_i^s denote the change in the technological knowledge level of firm *i* due to KD. Therefore, the technological knowledge level of the firms at the end of the second stage will be as Eq. (4):

$$K_{i2}^s = K_{i1}^s + KD_i^s = K_{i0} + \beta_i K_{new}^s + KD_i ; i = 1,2; s = 1,2 \quad (4)$$

4.2. *Expected profit.*

The Common part of the firm's expected net revenue has four main components: 1-loyal customer's valuation, 2- switching customer's valuation, 3- and the probability that each firm is alone in the market at the end of stage 2, i.e., its competitor does not develop a new product by the end of that stage, and 4- having a market share of innovators and early adopters.

- Loyal customer's valuation. This part of the revenue is earned from customers who buy from their expected company without comparing their competitors' level of technological knowledge Ozkan [1]. Therefore, when the new product is released to the market, the revenue earned from loyal customers at the end of stage 2 is Eq. (5):

$$\pi_1 = \sum_{s=1}^{2}\sum_{i=1}^{2} p_s \delta_i^s Z_i K_{i2}^s \quad (5)$$

where π_1 is the expected profit of loyal customers and p_S is the probability of scenario s.

- The second part of the expected net revenue represents the customers who purchase based on the technological knowledge level used in the product. OZKAN [1] refers to these as "switching customers". Therefore, the increase or decrease of the expected net revenue due to switching customers (π_2) is as Eq. (6):

$$\pi_2 = \sum_{s=1}^{2}\sum_{i=1}^{2}\sum_{n\neq i}^{2} p_s \delta_i^s \delta_n^s \varphi_i (K_{i2}^s - K_{n2}^s) \qquad (6)$$

If only one firm acquires the technological knowledge at the end of the second stage, it is recognized as a monopolist and earns more revenue from the market. Thus, π_3 is the expected net revenue of the firms due to the additional market share (Eq. (7)).

$$\pi_3 = \sum_{s=1}^{2}\sum_{i=1}^{2}\sum_{n\neq i}^{2} p_s \delta_i^s (1-\delta_n^s) \mu_i K_{i2}^s \qquad (7)$$

- Finally, if a firm reaches the technological knowledge of the NPD sooner, it can capture the share of innovators and early adopters. This means that the customers of these groups, which constitute 16 percent of the total market demand, are waiting for a new product to buy, and the first-mover can make use of this advantage. Here, for simplicity, we assume that the remaining demand for the product is provided by the product demand function, which will be discussed in the third stage. So, the first-mover will gain 16% of the total demand share, which we consider *V*, and the first part of the profit will be:

If they simultaneously acquire the technological knowledge, the profit will be divided between the two firms (π_4) as Eq. (8):

$$\pi_4 = \frac{V}{2}(x_{11}^H + x_{21}^H) \qquad (8)$$

where x_{ij}^H denotes the decision variable: if firm *i* in period *j* of the first stage acquires technological knowledge simultaneously, it is 1; otherwise 0, $i, j \in \{1,2\}$.

If technological knowledge acquisition is sequential, then the profit is for the leader:

$$\pi_4 = V(x_{11}^T + x_{21}^T) \qquad (9)$$

Where in the Eq. (9), x_{ij}^T denotes the decision variable: if firm *i* in period *j* of the first stage acquires technological knowledge sequentially, it is 1; otherwise *0*, $i, j \in \{1,2\}$

So the expected profit (π) is (Eq. (10)):

$$\pi = \pi_1 + \pi_2 + \pi_3 + \pi_4 \quad (10)$$

4.3. *Costs*

In the first stage, the cost incurred by the firms will be due to the cost of technological knowledge acquisition ($I_\circ$). This cost differs depending on the first movement or the second: if both firms (in period 1 or 2) gain technological knowledge in the first stage, the acquisition cost will be the same for both and equal to I ; if technological knowledge acquisition is sequential and one firm gains technological knowledge in the first and the other during the second period, the cost of technological knowledge acquisition will be lower for the second-mover due to its learning from the first-mover (Table **6**).

Parameter $L \in \{0,1\}$ represents the advantage of learning. Learning makes the technological knowledge acquisition cost lower for the second-mover in period 2. As the two firms get closer, *L* gets closer to *1*. Thus, the cost of technological knowledge acquisition is:

$$C_A = I_0 \sum_i^2 \sum_j^2 x_{ij}^H + \sum_i^2 I_0 x_{i1}^T + I_0 (1-L) \sum_i^2 x_{i2}^T \quad (11)$$

Where in the Eq. (11), C_A denote technological knowledge acquisition cost.

In acquiring new technological knowledge, there is a risk-driven uncertainty, which depends on the first technological knowledge level of firms and the period of new technological knowledge selection. We denote by r_{ij} the risk of new technological knowledge selection for firm *i* in period j. C_R denotes the risk cost of new technological knowledge selection in Eq. (12):

$$C_R = \sum_i^2 \sum_j^2 r_{ij} (x_{ij}^H + x_{ij}^T) \qquad (12)$$

We consider the technological KD cost in the second stage, which depends on the technological knowledge level at the start of the second stage. In the this stage, each firm undertakes a marginal cost to produce the product. So C_D is equal to:

$$C_D = \sum_s^2 \sum_i^2 p_s \omega_i^s KD_i^s \quad (13)$$

Where in the Eq. (13), ω_i^s is the cost of developing technological knowledge for the production of the firm *i* in the second stage under the scenario *S*. So the total cost (C) is (Eq. (14)):

$$C = C_A + C_R + C_D \qquad (14)$$

4.4. *Technological knowledge level and marginal cost*

The higher technological knowledge level and the greater absorption coefficient will lead to lower marginal cost in producing. Given that the level of new technological knowledge is uncertain, firms will know their marginal cost after receiving it. So, assume that the relationship between the marginal cost and the level of technological knowledge of the participants is:

$$c_i^s = \frac{\gamma}{\beta_i K_{new}^s + K_{i0} + KD_i^s} \qquad (15)$$

In Eq. (15), $S \in \{1, 2\}$ is the predicted scenarios for the new technological knowledge level, c is the marginal cost of each firm in production, and γ is the coefficient of converting technological knowledge to the marginal cost of each firm.

4.5. *Demand*

The market is duopoly and two firms supply the total demand. In the model, we use a linear demand function widely used in economics and marketing literature: (e.g. [35-40])

$$P(Q) = \theta - Q = \theta - (q_1 + q_2) \quad (16)$$

In the Eq. (16), P is the product, θ is the constant demand number, Q is the total supply from the two suppliers and q_i the production quantity of firm *i* on the market.

4.6. *Model Objective Function*

$$Z = Min(C - \pi) = I_0 \left[\sum_{i}^{2} \sum_{j}^{2} x_{ij}^{H} + \sum_{i}^{2} x_{i1}^{T} + (1-L) \sum_{i}^{2} x_{i2}^{T} \right] -$$

$$V(x_{11}^{T} + x_{21}^{T}) - \frac{V}{2}(x_{11}^{H} + x_{21}^{H}) + \sum_{i}^{2} \sum_{j}^{2} r_{ij}(x_{ij}^{H} + x_{ij}^{T}) +$$

$$\sum_{s}^{2} p_s \Big(\sum_{i}^{2} \omega_i^s KD_i^s - \sum_{i}^{2} \delta_i^s Z_i K_{i2}^s - \sum_{i}^{2} \sum_{n \neq i}^{2} \delta_i^s \delta_n^s \varphi_i (K_{i2}^s - K_{n2}^s) - \sum_{i}^{2} \sum_{n \neq i}^{2} \delta_i^s (1 - \delta_n^s) \mu_i K_{i2}^s \Big)$$

(17)

Constraint:

$$\sum_{j}^{2} (x_{ij}^{H} + x_{ij}^{T}) = 1; \forall i \qquad (18)$$

$$\sum_{j}^{2} I_0 (x_{ij}^{H} + x_{ij}^{T}) + \omega_i^s KD_i^s \leq B_i; \forall i, s \qquad (19)$$

$$K_{i2}^s = K_{i0} + \beta_i K_{new}^s + KD_i^s; \forall i, s \qquad (20)$$

$$x_{ij}^{H} = x_{nj}^{H}; \forall i, j; i \neq n \qquad (21)$$

$$x_{ij}^{T} = x_{nm}^{T}; \forall i, j; i \neq n; j \neq m \qquad (22)$$

$$x_{ij}^{H}, x_{ij}^{T} \in \{0,1\}; KD_i^s \geq 0; \forall i, j, s \qquad (23)$$

The *Eq. (17)* defines the expected revenue and cost of the firms. The Constraint (*18*) describes the decision-making process: simultaneously or sequentially. Constraint (*19*) specifies the firm's budget limitation , where B_i is the total budget of firm *i*. The Constraint (*20*) states the level of the final technological knowledge of the firms at the end of the second stage. The Constraint (*21*) shows that if the first firm decides in each period simultaneously to acquire technological knowledge, then the second firm chooses the technological knowledge at the same time. Equivalently, the Constraint (*22*) state that if the first firm decides in a sequential manner in each period, the second firm will choose technological knowledge in the opposite period And finally, the Constraint (23) specifies the feasible solution space.

4.6.1. The proposed robust model

The Eq. (24) is objective functions of the robust counterpart model and constraints (25) to (31) represent the corresponding constraints of the robust counterpart model in the proposed model.

$$Z = Min(C-\pi) = I_0\left[\sum_{i}^{2}\sum_{j}^{2} x_{ij}^{H} + \sum_{i}^{2} x_{i1}^{T} + (1-L)\sum_{i}^{2} x_{i2}^{T}\right] -$$
$$V(x_{11}^{T} + x_{21}^{T}) - \frac{V}{2}(x_{11}^{H} + x_{21}^{H}) + \sum_{i}^{2}\sum_{j}^{2} r_{ij}(x_{ij}^{H} + x_{ij}^{T}) +$$
$$\sum_{s}^{2} p_s(\sum_{i}^{2}\varpi_i^s KD_i^s - \sum_{i}^{2}\delta_i^s Z_i K_{i2}^s - \sum_{i}^{2}\sum_{n\neq i}^{2}\delta_i^s\delta_n^s\varphi_i(K_{i2}^s - K_{n2}^s) - \sum_{i}^{2}\sum_{n\neq i}^{2}\delta_i^s(1-\delta_n^s)\mu_i K_{i2}^s) +$$
$$\sum_{i}^{2}\sum_{s}^{2} p1_{is}^{\omega} + \Gamma^{\omega}\lambda 1^{\omega}$$
(24)

Constrains:

$$p1_{is}^{\omega} + \lambda^{\omega} \geq p_s\widehat{\omega}_i^s KD_i^s \forall i,s \qquad (25)$$

$$\sum_{j}^{2}(x_{ij}^{H} + x_{ij}^{T}) = 1; \forall i \qquad (26)$$

$$\sum_{j}^{2} I_0(x_{ij}^{H} + x_{ij}^{T}) + \widehat{\omega}_i^s KD_i^s + p2_{is}^{\omega} + \lambda 2_{is}^{\omega}\Gamma_{is}^{\omega} \leq B_i; \forall i,s \qquad (27)$$

$$p2_{is}^{\omega} + \lambda 2_{is}^{\omega} \geq KD_i^s\widehat{\omega}_i^s; \forall i,s \qquad (28)$$

$$K_{i2}^s = K_{i0} + \beta_i K_{new}^s + KD_i^s; \forall i,s \qquad (29)$$

$$x_{ij}^{H} = x_{nj}^{H}; \forall i,j; i\neq n \qquad (30)$$

$$x_{ij}^{T} = x_{nm}^{T}; \forall i,j; i\neq n; j\neq m \qquad (31)$$

4.6.2. Robust budget adjustment.

Consider the Robust counterpart model, each of the constraints (*27*) has only one non-deterministic parameter in the corresponding constraint. The maximum steady budget (Γ_{is}^{ω}) is the limit of one and at least equal to *zero*. For convenience, for a random parameter ω_i^s, a total steady budget is determined and the contribution of each limitation to the total budget is considered.

4.6.3. Benders decomposition algorithm

To apply the Benders algorithm to formulate the model, the sub-problem (Eq. (32) and Constrains (33) to (36)) and its dual (Eq. (37) and Constrains (38) to (43)), the main problem (Eq. (44) and Constrains (45) to (48)), and finally the optimal cut of the Benders are as follows.

- **Sub Problem**

$$Min(SP) = \sum_{s}^{2} p_s(\sum_{i}^{2}\varpi_i^s KD_i^s - \sum_{i}^{2}\delta_i^s Z_i K_{i2}^s - \sum_{i}^{2}\sum_{n\neq i}^{2}\delta_i^s\delta_n^s\varphi_i(K_{i2}^s - K_{n2}^s) - \sum_{i}^{2}\sum_{n\neq i}^{2}\delta_i^s(1-\delta_n^s)\mu_i K_{i2}^s) +$$
$$\sum_{i}^{2}\sum_{s}^{2} p1_{is}^{\omega} + \Gamma^{\omega}\lambda 1^{\omega}$$
(32)

Constrains:

$$p1_{is}^{\omega} + \lambda^{\omega} \geq p_s \widehat{\omega}_i^s KD_i^s \forall i, s \qquad (33)$$

$$\sum_j^2 I_0 (x_{ij}^H + x_{ij}^T) + \varpi_i^s KD_i^s + p2_{is}^{\omega} + \lambda 2_{is}^{\omega} \frac{\Gamma^{\omega}}{I * S} \leq B_i ; \forall i, s \qquad (34)$$

$$p2_{is}^{\omega} + \lambda 2_{is}^{\omega} \geq KD_i^s \widehat{\omega}_i^s ; \forall i, s \qquad (35)$$

$$K_{i2}^s = K_{i0} + \beta_i K_{new}^s + KD_i^s ; \forall i, s \qquad (36)$$

- **Dual SP.** To write the dual sub problem, the variablesb $D1_{is}$, $D2_{is}$, $D3_{is}$ and $D4_{is}$ are considered for each of the SP constraints. The *DSP* is written as follows:

$$Max(DSP) = \sum_i^2 \sum_j^2 D2_{is} (I_0 (\overline{x}_{ij}^H + \overline{x}_{ij}^T) - B_i) - \sum_i^2 \sum_j^2 D4_{is} (K_{i0} + \beta_i K_{new}^s) \qquad (37)$$

Constrains:

$$D1_{is} \leq 1; \forall i, s \quad (38)$$

$$\sum_{i,s}^2 D1_{is} \leq \Gamma^{\omega} \quad (39)$$

$$-D2_{is} + D3_{is} \leq 0; \forall i, s \qquad (40)$$

$$-(\frac{\Gamma^{\omega}}{I * S}) D2_{is} + D3_{is} \leq 0; \forall i, s \quad (41)$$

$$-p_s \widehat{\omega}_i^s D1_{is} - \varpi_i^s D2_{is} - \widehat{\omega}_i^s D3_{is} + D4_{is} \leq p_s \varpi_i^s \quad (42)$$

$$-D4_{is} \leq -\delta_i^s Z_i - \delta_i^s \delta_n^s \varphi_i - \delta_i^s (1 - \delta_n^s) \mu_i ; \forall i, j, i \neq n \qquad (43)$$

- **MP Problem**

$$\begin{aligned} Min(MP) = \pi + I_0 \left[\sum_i^2 \sum_j^2 x_{ij}^H + \sum_i^2 x_{i1}^T + (1 - L) \sum_i^2 x_{i2}^T \right] - \\ V(x_{11}^T + x_{21}^T) - \frac{V}{2} (x_{11}^H + x_{21}^H) + \sum_i^2 \sum_j^2 r_{ij} (x_{ij}^H + x_{ij}^T) \end{aligned} \qquad (44)$$

Constrains:

$$\sum_i^2 \sum_j^2 D2_{is} (I_0 (\overline{x}_{ij}^H + \overline{x}_{ij}^T) - B_i) - \sum_i^2 \sum_j^2 D4_{is} (K_{i0} + \beta_i K_{new}^s) \leq \pi \qquad (45)$$

$$\sum_j^2 (x_{ij}^H + x_{ij}^T) = 1; \forall i \qquad (46)$$

$$x_{ij}^{H} = x_{nj}^{H}; \forall i, j; i \neq n \qquad (47)$$

$$x_{ij}^{T} = x_{nm}^{T}; \forall i, j; i \neq n; j \neq m \qquad (48)$$

Benders decomposition algorithm

```
{Initialization}
Set Eq. (49) as initial feasible integer solution
$(\overline{x}_{ij}^{H}, \overline{x}_{ij}^{T})$          (49)
$LB = -\infty, UB = +\infty, \dot{L} = \dot{K} = 0, while(UB - LB \geq \varepsilon)DO$          (50)
{Solve Sub-Problem}
If (Sub-Problem is Unbounded) then
Get unbounded ray µ
Add cut Constraint (46) To master problem and run Eq. (51)
$\dot{L} = \dot{L} + 1$          (51)
Else
Get extreme point µ
Add cut Constraint (45) To master problem  and run Eq. (52):
$\dot{K} = \dot{K} + 1, UB = Min\left\{ \begin{array}{l} UB, I_0\left[\sum_{i}^{2}\sum_{j}^{2} x_{ij}^{H} + \sum_{i}^{2} x_{i1}^{T} + (1-L)\sum_{i}^{2} x_{i2}^{T}\right] - \\ V(x_{11}^{T} + x_{21}^{T}) - \frac{V}{2}(x_{11}^{H} + x_{21}^{H}) + \sum_{i}^{2}\sum_{j}^{2} r_{ij}(x_{ij}^{H} + x_{ij}^{T}) + DSP.l \end{array} \right\}$          (52)
End if
{Solve master problem}
$LB = \pi$          (53) // results of master problem
End while
```

As is clear from this pseudocode, first, we must find a feasible solution to the main problem. This is done by solving the main problem without any cutting plane (Eq. (49)). Then, the solutions obtained from the main problem are given to the SP (Eq. (50)), and this problem is solved. If the SP is not feasible and the dual is unlimited, then an infinite direction is taken from the dual and is produced using the direction of a cut. This cut is added to the main problem.

4.6.4. The numerical example

Using nominal data, the game theory-based mixed-integer problem under deterministic and robust conditions has been coded by the Benders optimization algorithm in GAMS software. The obtained results are reported in the following. The deterministic and robust models have been compared at three different levels of maximum violation probability (*Pr = 0.1, 0.15, 0.2*) and three deviation rates from nominal data (*5%, 10%, 15%*). The solutions of the deterministic and robust models are given in the following tables. According to Table 7, Table 8 and Table 9 it can be said that by the reduction of the constraint violation probability, the robust model has been worsened step by step. Figure 4 shows the trend of the robust model changes against the maximum violation probability at the level of 5% deviation from the nominal data.

As can be seen, by the reduction of the maximum violation probability (the increase of the conservation level), the robust model has been worsened at each step. The objective function is a minimization one and thus its increase is undesirable. By the deterministic model, we mean the initial model that includes non-deterministic parameters instead of which nominal values are replaced. Thus, the maximum violation probability and deviation percentages from the nominal data have no impact on the deterministic model. On the other hand, by the increase of the deviation from the nominal values, the robust model has been worsened at each step. In Figure 5 , the robust model changes against the deviation from the nominal values at the maximum constraint violation probability 10% has been shown.

The increase of the deviation from the nominal data has had a negative effect on the robust model. By this increase, we are interested to know what will happen if the uncertainty ranges of the non-deterministic parameter increases. Thus, if this range is estimated correctly and it reduces considerably, the negative effects can be mitigated.

In specific dimensions, in each state of the sensitivity analysis, both models converged in about 15 iterations. As can be seen in Figure 6 and Figure 7, the lower bound has increased regularly, while the upper bound has experienced a non-regular trend and finally the algorithm converged. Figure 6 displays how the robust model has converged at the maximum violation probability 0.2 and deviation 10%. Figure 7**Error! Reference source not found.** shows this for the deterministic model.

Solving this model helps determine whether the technological knowledge acquisition process is simultaneous or sequential as well as the technological knowledge amount at the end of the second stage.

4.7. ***Market Structure***

As stated in the section 3.5, the stochastic programming model determines the game type (simultaneous or sequential) and marginal cost. Thus, we have:

4.7.1. The technological knowledge acquiring process is simultaneous.

In this case, we consider a game with the following properties:

- Players: firm *1* and *2*
- Strategies: Production amount in the marketplace (q_i)
- Payoffs: The profits of each firm from selling products in the market:
- $(\pi_i = [P - c] * q_i)$, where π_i is the profit of the firm *i* and *P* is the price of selling the product on the market)

By solving this game, we will have Eq.(54):

$$q_i = \frac{\theta + c_j - 2c_i}{3} ; \forall i, j, i \neq j \qquad (54)$$

4.7.2. The technological knowledge acquiring process is sequential

Here, we assume that firm 1 (the leader), who gain new technological knowledge in the first period from the first stage, determines q_1 and then the follower (firm 2) will decide on the amount of its production (q_2) in the market. Here, we have Eq. (55):

$$q_1 = \frac{\theta + c_2 - 2c_1}{2}, q_2 = \frac{\theta - 3c_c + 2c_1}{4} \qquad (55)$$

4.7.3. One firm does not enter the technological knowledge gaining process

We assume that firm *j* does not choose the new technological knowledge. In this case, this firm can use its old technological knowledge.

5. Numerical analysis.

To solve the proposed model, we use the research data [1] and [41]. Table **10** shows the data of this example. In this example, it is assumed that the first technological knowledge and its absorption coefficient are greater for firm *1*. We estimate the firm budget based on the investment rate and the technological knowledge level of the firms. We solved the stochastic programming model by the GAMS software, the results of which are shown in Table 11 and Table 12. The results show that the choice of new technological knowledge is sequential and the second firm will gain the technological knowledge as a leader in the first period. Although the first firm has a higher level of technological knowledge and a lower risk of choosing the new technological knowledge, the second firm, due to its high learning rate that causes it lower cost, will act as a pioneer in the gaining of the technological knowledge. The sensitivity analysis of the model shows that with a slight change in the learning coefficient, the choice of firms will undergo many changes.

In relation to the second stage variables, as shown in Table 12, in the first scenario, where the new technological knowledge level is low, the technological KD is more than the second scenario. This difference means that when the new technological knowledge level is low, firms need to develop greater technological knowledge to reach the desired level of technological knowledge for launching their new product. Table **12** shows the total technological knowledge level of each firm at the end of the second stage. A firm with more technological knowledge will produce its product at a lower cost.

According to the stochastic programming model, the second firm as a leader, with a lower level of first technological knowledge, will gain new technological knowledge and enters the market sooner. The Stackelberg game determines the market share for each firm, as shown in Table **13**, and the winning firm is shown in Table **14**. The analysis of the results shown in Table **14** is interesting since it is clear that factors such as the technological knowledge level, technological knowledge converting coefficient, and constant demand number play a decisive role in determining the final market winner. These results suggest that although a firm may be a leader in acquiring a leading technological knowledge, it will not necessarily win the market. This is a reality that is often observed in the real world. For example, in 2013 Google launched Google Glass, the head-mounted wearable computer as a first-mover, but the product was discontinued in 2015. Later, numerous companies have picked it up where Google left it [42].

6. Managerial implication

This study suggests that the competition, uncertainty, investment time, and knowledge level of firms have the strongest influence on the decision to acquire new knowledge. One of the managerial implications of the results and discussion is the need for the organization to decide on heavy investments in uncertainty. Investing in new knowledge is a two-pronged decision, just as it can create a competitive advantage for the organization, it can also lead to failure, and managers play a key role in this. In this decision, managers need:

a. Assess the quality level of new knowledge and its relationship with the existing knowledge of the organization.
b. Determine the amount of capital needed for KD.
c. Assess competitors and choose the optimal time to acquire knowledge.
d. Determine the optimal amount of production in the market.

Therefore, managers must consider several factors to be successful in the market. The outcomes of this research, if utilized properly, can be utilized as a decision support tool for firms to find the optimal timing of the adoption of cost-reducing technological knowledge. This tool will help managers of organizations to choose the best time to invest and make the most profit in the market, given the uncertainty of new knowledge as well as the existing level of knowledge of the firm.

7. Conclusion

This study was undertaken to suggest an efficient solution for deciding how to acquire new technical knowledge. We introduced a two-stage stochastic programming model that explores Knowledge Management (KM) strategies that drive NPD for two profit-maximizing firms. The KM strategies included the KT between the firms and the KD pursued by each firm independent of its competitor. After determining the technological knowledge acquisition strategy, the leader-follower and the production cost, they enter a game theory model to determine the amount of the product in the market. This novel two-stage stochastic programming and game theory model has been developed to determine the competition equilibrium between two firms in adoption and developing new knowledge. The proposed model considers the process of adoption and developing a knowledge and according to various factors such as firms 'budgets, new knowledge uncertainty, firms' current level of knowledge, risk of early market entry, branding advantage and product demand in the market, determines the best time to acquire new knowledge.

In this study, we examined how adoption and developing new knowledge reduces production costs and increases market competitiveness. The initial level of knowledge of firm, by adoption new knowledge and developing it, will reach a level that can be used to produce and market it.

In the proposed model, we considered branding as an advantage of earlier knowledge acquisition. In this way, any firm that absorbs knowledge sooner will gain more market share. This advantage includes loyal customer’s valuation, switching customer’s valuation, and the probability that each firm is alone in the market and having a market share of innovators and early adopters. On the other hand, the second firm, by learning from the entry of the first can absorb knowledge at a lower cost. We considered the risk of acquiring knowledge early .The risk of selecting new technological knowledge is lower for a firm that has a higher level of technological knowledge. Also, the risk becomes lower if the choice of new technological knowledge is postponed because of the time spent in acquiring technological knowledge. Finally, firms enter the market using the acquired and developed knowledge to determine the amount of production by Cournot and Stackelberg game theory model .We assume that demand is linearly related to price, firms 'products are homogeneous, and that production cost is inversely related to firms' total knowledge at the time of production.

The results of stochastic programing and game theory model show that the level of knowledge of firms at the time of production, knowledge absorption coefficient, and constant demand coefficient will have a special effect on determining the winner in the market. These results show that although a firm may be a leader in acquiring a leading technological knowledge, it will not necessarily win the market. As shown in Table **14**, while the second firm has a lower technological knowledge level and a lower risk, it chooses new technological knowledge sooner due to the advantage of innovative customers. But, considering the production cost and market demand conditions, the final winner in the market may be determined regardless of the benefit of the first movement.

8. Future Study

New knowledge adoption is a strategic decision that involves a variety of dimensions. This decision is based on four levels: new knowledge, firm, competitive environment and the market. At the level of new knowledge, its fitness to the firm's capabilities is very important and the need for knowledge assessment is based on external and internal factors. At the firm level, the initial knowledge of the firm has a great impact on the success of knowledge acquisition and product development in the market. Competition and the time of new knowledge adoption and methods of acquiring it are the main factors of the competitive environment. Ultimately, the uncertainty that exists in new knowledge, the competitive environment, and the market will affect the success or failure of the acquisition of new knowledge. To this end, many models for optimal decision making of the new knowledge acquisition by researchers to consider the above factors have been used that can be referred to financial and non-financial methods.

Our work has some limitations that should be addressed in future work. The following are suggested for future studies:

- At the level of new knowledge, the selection of knowledge among the appropriate options is not considered in this work. A model that examines the selection of knowledge among several options can provide better results for firms.

- Each of these alternatives will have a different cost, proportionality factor with the firm's current knowledge, and uncertainty, which can have an impact on the firm's knowledge acquisition strategy.
- In the literature of knowledge sourcing, there are several ways to acquire a knowledge, each with its own characteristics. These methods include domestic research and development, equity R&D joint venture, joint venture, equity R&D consortium, complementary license purchase, license purchase, Sub-contracted R&D, Firm take-over, cross licensing and joint take-over. In this work, the mode of acquiring knowledge is not considered. While each of these modes is very important in the knowledge acquisition strategy of firms.

9. References

1. Ozkan, G.F. "Essays on knowledge management strategies in new product development", PhD Thesis, Georgia Institute of Technology, *Georgia Institute of Technology ProQuest Dissertations Publishing, (2009)*

2. Hoppe, H.C. "Second-mover advantages in the strategic adoption of new technology under uncertainty", *International Journal of Industrial Organization*, pp. 315-338 (2000)

3. Agarwal, R. and Gort, M. "The Evolution of Markets and Entry, Exit and Survival of Firms", *The Review of Economics and Statistics*, **78**(3), pp. 489-498 (1996)

4. Lieberman, M.B. and Montgomery, D.B. "First-mover advantages", *Strategic Management Journal*, **9**(S1), pp. 41-58 (1988)

5. Leiblein, P.M.J., Chen, P.J.S., and Posen, P.H.E. "Uncertain Learning Curves: Implications for First Mover Advantage and Knowledge Spillovers", *Academy of Management Review*, **0**(ja), pp. null (2021)

6. Li, R., Zheng, L., and Yuan, L. "TMT's decision-making on adoption of management innovation", *Journal of Organizational Change Management*, **35** (7), pp. 1061-1088 (2022)

7. Golder, P.N. and Tellis, G.J. "Pioneer Advantage: Marketing Logic or Marketing Legend?", *Journal of Marketing Research*, **30**(2), pp. 158-170 (1993)

8. Ballard, S.C. and Hall, T.A. "Theory and practice of integrated impact assessment: The case of the western energy study", *Technological Forecasting and Social Change*, **25**(1), pp. 37-48 (1984)

9. Banuls, V.A. and Salmeron, J.L. "A Scenario-Based Assessment Model—SBAM", *Technological Forecasting and Social Change*, **74**(6), pp. 750-762 (2007)

10. Keller, P. and Ledergerber, U. "Bimodal System Dynamic A Technology Assessment and Forecasting Approach", *Technological Forecasting and Social Change*, **58**(1), pp. 47-52 (1998)

11. Palm, E. and Hansson, S.O. "The case for ethical technology assessment (eTA)", *Technological Forecasting and Social Change*, **73**(5), pp. 543-558 (2006)

12. Wilhite, A. and Lord, R. "Estimating the risk of technology development", *Engineering Management Journal*, **18**(3), pp. 3-10 (2006)

13. Winebrake, J.J. and Creswick, B.P. "The future of hydrogen fueling systems for transportation: An application of perspective-based scenario analysis using the analytic hierarchy process", *Technological Forecasting and Social Change*, **70**(4), pp. 359-384 (2003)

14. Wolstenholme, E.F. "The use of system dynamics as a tool for intermediate level technology evaluation: three case studies", *Journal of Engineering and Technology Management*, **20**(3), pp. 193-204 (2003)

15. McDonald, A. and Schrattenholzer, L. "Learning curves and technology assessment", *International Journal of Technology Management*, **23**(7-8), pp. 718-745 (2002)

16. Giovanis, A., Athanasopoulou, P., Assimakopoulos, C., et al. "Adoption of mobile banking services: A comparative analysis of four competing theoretical models", *International Journal of Bank Marketing*, **37**(5), pp. 1165-1189 (2019)

17. Le Mare, L. and Audet, K. "Communicative openness in adoption, knowledge of culture of origin, and adoption identity in adolescents adopted from Romania", *Adoption Quarterly*, **14**(3), pp. 199-217 (2011)

18. MURTO, P. and KEPPO, J. "A GAME MODEL OF IRREVERSIBLE INVESTMENT UNDER UNCERTAINTY", *International Game Theory Review*, **04**(02), pp. 127-140 (2002)

19. Parramore, K. "Technology investment: a game theoretic real options approach", *Technovation*, **23**(11), pp. 901-901 (2003)

20. PETIT, M.-L., SANNA-RANDACCIO, F., and TOLWINSKI, B. "INNOVATION AND FOREIGN INVESTMENT IN A DYNAMIC OLIGOPOLY", *International Game Theory Review*, **02**(01), pp. 1-28 (2000)

21. Xue, Y. and Pan, D. “Analysis of Enterprise¡¯s XBRL Technology Adoption Based on Evolutionary Game Theory”, *Modern Economy*, **Vol.09No.12**, pp. 14 (2018)

22. Yeung, D.W.K. and Petrosyan, L.A. “A Cooperative Dynamic Environmental Game of Subgame Consistent Clean Technology Development”, *International Game Theory Review*, **18**(02), pp. 1640008 (2016)

23. Aboelmaged, M. and Hashem, G. “Absorptive capacity and green innovation adoption in SMEs: The mediating effects of sustainable organisational capabilities”, *Journal of Cleaner Production*, **220**, pp. 853-863 (2019)

24. Zhao, T. and Liu, Z. “A novel analysis of carbon capture and storage (CCS) technology adoption: An evolutionary game model between stakeholders”, *Energy*, **189**, pp. 116352 (2019)

25. Yuan, H. and Yang, Y. “BIM Adoption under Government Subsidy: Technology Diffusion Perspective”, *Journal of Construction Engineering and Management*, **146**(1), pp. 04019089 (2020)

26. Mateos-Planas, X. “Technology adoption with finite horizons”, *Journal of Economic Dynamics and Control*, **28**(11), pp. 2129-2154 (2004)

27. Skare, M. and Riberio Soriano, D. “How globalization is changing digital technology adoption: An international perspective”, *Journal of Innovation & Knowledge*, **6**(4), pp. 222-233 (2021)

28. Chiesa, V. “R&D strategy & organisation: Managing technical change in dynamic contexts”, Imperial College Press, *London (2001)*

29. Adamauskas, S. and Krušinskas, R.“Mobile 5g Technology Adoption Investment Timing Decision Makers Clustering And Willingness To Invest Under Volatile Demand Changes”, *in CBU International Conference Proceedings*.of Conference, (2016)

30. Brown, S. “Managing process technology—further empirical evidence from manufacturing plants”, *Technovation*, **21**(8), pp. 467-478 (2001)

31. Karami Poor, A., Jolly, D., and Boly, V. “Determinants of technology sourcing modes in Iranian hi-tech companies”, *Iranian journal of management sciences*, **8**(32), pp. 111-138 (2013)

32. Dale, V., McEwan, M., and Bohan, J. “Early adopters versus the majority: Characteristics and implications for academic development and institutional change”, *Journal of Perspectives in Applied Academic Practice*, **9**(2), pp. 54-67 (2021)

33. Wang, X., Cho, S.-H., and Scheller-Wolf, A. “Green technology development and adoption: competition, regulation, and uncertainty—a global game approach”, *Management Science*, **67**(1), pp. 201-219 (2021)

34. Sylla, C. and Wen, H.J. “A conceptual framework for evaluation of information technology investments”, *International Journal of Technology Management*, **24**(2-3), pp. 236-261 (2002)

35. Gal-Or, E. “Information Sharing in Oligopoly”, *Econometrica*, **53**(2), pp. 329-343 (1985)

36. Li, L. “Information Sharing in a Supply Chain with Horizontal Competition”, *Management Science*, **48**(9), pp. 1196-1212 (2002)

37. Mukhopadhyay, S.K., Yue, X., and Zhu, X. “A Stackelberg model of pricing of complementary goods under information asymmetry”, *International Journal of Production Economics*, **134**(2), pp. 424-433 (2011)

38. Raju, J.S. and Roy, A. “Market Information and Firm Performance”, *Management Science*, **46**(8), pp. 1075-1084 (2000)

39. Tsay, A.A. and Agrawal, N. “Channel Dynamics Under Price and Service Competition”, *Manufacturing & Service Operations Management*, **2**(4), pp. 372-391 (2000)

40. Vives, X. “Duopoly information equilibrium: Cournot and bertrand”, *Journal of Economic Theory*, **34**(1), pp. 71-94 (1984)

41. Patel, P. “Essays in technology adoption and corporate finance”, PhD Thesis, UC Berkeley, *(2013)*

42. ROSMAN, M."First-Mover Disadvantage: 9 Reasons Why Being First to Market Doesn't Pay Off", *IN INNOVATION,Revelx*. Available from: https://www.revelx.co/blog/first-mover-disadvantage/. (2020)

43. Anderson, S.T. and Newell, R.G. "Information programs for technology adoption: the case of energy-efficiency audits", *Resource and Energy economics*, **26**(1), pp. 27-50 (2004)

44. Angelis, A., Lange, A., and Kanavos, P. "Using health technology assessment to assess the value of new medicines: results of a systematic review and expert consultation across eight European countries", *The European Journal of Health Economics*, **19**, pp. 123-152 (2018)

45. Batz, F.J., Janssen, W., and Peters, K.J. "Predicting technology adoption to improve research priority—setting", *Agricultural economics*, **28**(2), pp. 151-164 (2003)

46. Huggett, M. and Ospina, S. "Does productivity growth fall after the adoption of new technology?", *Journal of Monetary Economics*, **48**(1), pp. 173-195 (2001)

47. Spina, C. and Phetteplace, E. "Finding, evaluating, and sharing new technology", *Reference and User Services Quarterly*, **53**(3), pp. 217-220 (2014)

48. Swamidass, P.M. "Modeling the adoption rates of manufacturing technology innovations by small US manufacturers: a longitudinal investigation", *Research Policy*, **32**(3), pp. 351-366 (2003)

49. Karsh, S.M.A. "New technology adoption by business faculty in teaching: analysing faculty technology adoption patterns", *Education Journal*, **7**(1), pp. 5-15 (2018)

50. Chavez, D.E. and Chen, H. "First-mover advantages and innovation success: a contingency approach", *Journal of Business & Industrial Marketing*, **37**(6), pp. 1169-1181 (2022)

51. Christensen, C.M. "Exploring the limits of the technology S‐ curve. Part I: component technologies", *Production and operations management*, **1**(4), pp. 334-357 (1992)

52. Das, S. "The early bird catches the worm-first mover advantage through iot adoption for indian public sector retail oil outlets", *Journal of Global Information Technology Management*, **22**(4), pp. 280-308 (2019)

53. Hoppe, H.C. "The timing of new technology adoption: theoretical models and empirical evidence", *The Manchester School*, **70**(1), pp. 56-76 (2002)

54. Kopel, M. and Löffler, C. "Commitment, first-mover-, and second-mover advantage", *Journal of Economics*, **94**(2), pp. 143-166 (2008)

55. Przychodzen, W., Leyva‐ de la Hiz, D.I., and Przychodzen, J. "First‐ mover advantages in green innovation—Opportunities and threats for financial performance: A longitudinal analysis", *Corporate Social Responsibility and Environmental Management*, **27**(1), pp. 339-357 (2020)

56. Kamien, M.I. "Patent licensing", *Handbook of game theory with economic applications*, **1**, pp. 331-354 (1992)

57. Katz, M.L. and Shapiro, C. "On the licensing of innovations", *The RAND Journal of Economics*, pp. 504-520 (1985)

58. Kamien, M.I. and Tauman, Y. "The private value of a patent: A game theoretic analysis", Discussion Paper(1983)

59. Kamien, M.I. and Tauman, Y. "Fees versus royalties and the private value of a patent", *The Quarterly Journal of Economics*, **101**(3), pp. 471-491 (1986)

60. Kitagawa, T., Masuda, Y., and Umezawa, M. "Patent strength and optimal two-part tariff licensing with a potential rival", *Economics Letters*, **123**(2), pp. 227-231 (2014)

61. San Martín, M. and Saracho, A.I. "Patent strength and optimal two-part tariff licensing with a potential rival incorporating ad valorem royalties", *Economics Letters*, **143**, pp. 28-31 (2016)

62. Colombo, S. "A comment on "welfare reducing licensing"", *Games and Economic Behavior*, **76**(2), pp. 515-518 (2012)

63. Colombo, S. and Filippini, L. “Fee versus royalty licensing in a Cournot duopoly model with a commitment of no production”, *Economics Bulletin*, **33**(3), pp. 2122-2128 (2013)

64. Fauli-Oller, R. and Sandonis, J. “Welfare reducing licensing”, *Games and Economic Behavior*, **41**(2), pp. 192-205 (2002)

65. Li, Y. and Yanagawa, T. “Patent licensing of Stackelberg manufacturer in a differentiated product market”, *International Journal of Economic Theory*, **7**(1), pp. 7-20 (2011)

66. San Martín, M. and Saracho, A.I. “Royalty licensing”, *Economics Letters*, **107**(2), pp. 284-287 (2010)

67. Sen, D. and Tauman, Y. “General licensing schemes for a cost-reducing innovation”, *Games and Economic Behavior*, **59**(1), pp. 163-186 (2007)

68. Wang, X.H. “Fee versus royalty licensing in a differentiated Cournot duopoly”, *Journal of Economics and Business*, **54**(2), pp. 253-266 (2002)

69. Bloch, C. “R&D investment and internal finance: The cash flow effect”, *Economics of Innovation and New Technology*, **14**(3), pp. 213-223 (2005)

70. Monks, R.A. and Lajoux, A.R. “Corporate valuation for portfolio investment: Analyzing assets, earnings, cash flow, stock price, governance, and special situations”, John Wiley & Sons,*Bloomberg Perss, New Jersey (2010)*

71. Anandarajan, A. and Wen, H.J. “Evaluation of information technology investment”, *Management decision*, **37**(4), pp. 329-339 (1999)

72. Diakoulaki, D. and Karangelis, F. “Multi-criteria decision analysis and cost–benefit analysis of alternative scenarios for the power generation sector in Greece”, *Renewable and sustainable energy reviews*, **11**(4), pp. 716-727 (2007)

73. Mutenje, M.J., Farnworth, C.R., Stirling, C., et al. “A cost-benefit analysis of climate-smart agriculture options in Southern Africa: Balancing gender and technology”, *Ecological Economics*, **163**, pp. 126-137 (2019)

74. Harrison, M., Quisias, J., Frew, E.J., et al. “A Cost-Benefit Analysis of Teaching and Learning Technology in a Faculty of Pharmaceutical Sciences”, *American Journal of Pharmaceutical Education*, **83**(6) (2019)

75. Shimbar, A. and Ebrahimi, S.B. “Political risk and valuation of renewable energy investments in developing countries”, *Renewable Energy*, **145**, pp. 1325-1333 (2020)

76. Dobrowolski, Z. and Drozdowski, G. “Does the net present value as a financial metric fit investment in green energy security?”, *Energies*, **15**(1), pp. 353 (2022)

77. Panah, P.G., Bornapour, M., Cui, X., et al. “Investment opportunities: Hydrogen production or BTC mining?”, *International Journal of Hydrogen Energy*, **47**(9), pp. 5733-5744 (2022)

78. Isaias, J.C., Balestrassi, P.P., Marcondes, G.A.B., et al. “Project Portfolio Selection of Solar Energy by Photovoltaic Generation Using Gini-CAPM Multi-Criteria and Considering ROI Covariations”, *Energies*, **14**(24), pp. 8374 (2021)

79. Jeon, J.H., Choi, J.Y., Lee, S., et al. “Multiple ROI selection based focal liver lesion classification in ultrasound images”, *Expert Systems with Applications*, **40**(2), pp. 450-457 (2013)

80. Dogan, O. “Process mining technology selection with spherical fuzzy AHP and sensitivity analysis”, *Expert Systems with Applications*, **178**, pp. 114999 (2021)

81. Afrane, S., Ampah, J.D., Agyekum, E.B., et al. “Integrated AHP-TOPSIS under a fuzzy environment for the selection of waste-to-energy technologies in Ghana: a performance analysis and socio-enviro-economic feasibility study”, *International Journal of Environmental Research and Public Health*, **19**(14), pp. 8428 (2022)

82. Shardeo, V., Patil, A., and Madaan, J. “Critical success factors for blockchain technology adoption in freight transportation using fuzzy ANP–modified TISM approach”, *International Journal of Information Technology & Decision Making*, **19**(06), pp. 1549-1580 (2020)

83. Lin, S.-W. “The critical success factors for a travel application service provider evaluation and selection by travel intermediaries”, *Tourism management*, **56**, pp. 126-141 (2016)

84. Banias, O. “Test case selection-prioritization approach based on memoization dynamic programming algorithm”, *Information and Software Technology*, **115**, pp. 119-130 (2019)

85. Kun, L. and De, G.“An analysis of technology innovation investment based on options game theory”, *in 2010 IEEE International Conference on Advanced Management Science (ICAMS 2010).*of Conference, IEEE (2010)

86. Leclercq, L., Parzani, C., Knoop, V.L., et al. “Macroscopic traffic dynamics with heterogeneous route patterns”, *Transportation Research Procedia*, **7**, pp. 631-650 (2015)

87. Schwartz, E.S. and Zozaya-Gorostiza, C. “Investment under uncertainty in information technology: acquisition and development projects”, *Management Science*, **49**(1), pp. 57-70 (2003)

88. Wu, L.-C. and Ong, C.-S. “Management of information technology investment: A framework based on a Real Options and Mean–Variance theory perspective”, *Technovation*, **28**(3), pp. 122-134 (2008)

89. Caso, G., Alay, Ö., Ferrante, G.C., et al. “User-centric radio access technology selection: A survey of game theory models and multi-agent learning algorithms”, *IEEE Access*, **9**, pp. 84417-84464 (2021)

90. Esposito, C., Ficco, M., Palmieri, F., et al. “Smart cloud storage service selection based on fuzzy logic, theory of evidence and game theory”, *IEEE Transactions on computers*, **65**(8), pp. 2348-2362 (2015)

91. Jensen, R. “Innovation Adoption and Welfare Under Uncertainty”, *The Journal of Industrial Economics*, **40**(2), pp. 173-180 (1992)

92. Luong, N.C., Van, N.T.T., Feng, S., et al. “Dynamic network service selection in IRS-assisted wireless networks: A game theory approach”, *IEEE Transactions on Vehicular Technology*, **70**(5), pp. 5160-5165 (2021)

93. Van, N.T.T., Luong, N.C., Feng, S., et al. “Dynamic network service selection in intelligent reflecting surface-enabled wireless systems: Game theory approaches”, *IEEE Transactions on Wireless Communications*, **21**(8), pp. 5947-5961 (2022)

94. Kulatilaka, N. and Lin, L. “Impact of licensing on investment and financing of technology development”, *Management Science*, **52**(12), pp. 1824-1837 (2006)

95. May, D. “Cost-Benefit Analysis of Confidentiality Policies for Advanced Knowledge Management Systems”, Lawrence Livermore National Lab., CA (US)(2003)

96. Ruslan, S.Z.M. and Jaffar, M.M.“Analysis on net present value of joint ventures investment using diminishing musyarakah model”, *in 2012 International Conference on Statistics in Science, Business and Engineering (ICSSBE).*of Conference, IEEE (2012)

97. Dinmohammadi, A. and Shafiee, M. “Determination of the most suitable technology transfer strategy for wind turbines using an integrated AHP-TOPSIS decision model”, *Energies*, **10**(5), pp. 642 (2017)

98. Sarfaraz, A., Mukerjee, P., and Jenab, K. “Using fuzzy analytical hierarchy process (AHP) to evaluate web development platform”, *Management Science Letters*, **2**(1), pp. 253-262 (2012)

99. Lee, S., Kim, W., Kim, Y.M., et al. “Using AHP to determine intangible priority factors for technology transfer adoption”, *Expert Systems with Applications*, **39**(7), pp. 6388-6395 (2012)

100. Ismail Al- Alawi, A., Yousif Al- Marzooqi, N., and Fraidoon Mohammed, Y. “Organizational culture and knowledge sharing: critical success factors”, *Journal of knowledge management*, **11**(2), pp. 22-42 (2007)

101. McGrath, R.G. “A real options logic for initiating technology positioning investments”, *Academy of management review*, **22**(4), pp. 974-996 (1997)

102. Li, M. and Nguyen, B. “When will firms share information and collaborate to achieve innovation? A review of collaboration strategies”, *The Bottom Line*, **30**(1), pp. 65-86 (2017)

103. Li, M., Nguyen, B., and Yu, X. “Competition vs. collaboration in the generation and adoption of a sequence of new technologies: A game theory approach”, *Technology Analysis & Strategic Management*, **28**(3), pp. 348-379 (2016)

104. Okumura, Y. “Spatial competition and collaboration networks”, *International Journal of Game Theory*, **41**, pp. 455-472 (2012)

105. Rosenkranz, S. “Innovation and cooperation under vertical product differentiation”, *International Journal of Industrial Organization*, **13**(1), pp. 1-22 (1995)

106. Huang, Y.-S., Hsueh, T.-L., and Zheng, G.-H. “Decisions on optimal adoption time for new technology”, *Computers & Industrial Engineering*, **65**(3), pp. 388-394 (2013)

107. Pawlina, G. and Kort, P.M. “Real options in an asymmetric duopoly: Who benefits from your competitive disadvantage?”, *Journal of Economics & Management Strategy*, **15**(1), pp. 1-35 (2006)

108. Schniederjans, M.J., Hamaker, J.L., and Schniederjans, A.M. “Information technology investment: Decision-making methodology”, World Scientific Publishing Company, *Sinapore (2010)*

109. Trigeorgis, L. “Anticipated competitive entry and early preemptive investment in deferrable projects”, *Journal of Economics and Business*, **43**(2), pp. 143-156 (1991)

110. Xinhua, Z. and Wei, L. “Power producer's carbon capture investment timing under price and technology uncertainties”, *Energy Procedia*, **5**, pp. 1713-1717 (2011)

111. Angelou, G.N. and Economides, A.A. “A multi-criteria game theory and real-options model for irreversible ICT investment decisions”, *Telecommunications Policy*, **33**(10-11), pp. 686-705 (2009)

112. Fudenberg, D. and Tirole, J. “Preemption and Rent Equalization in the Adoption of New Technology”, *The Review of Economic Studies*, **52**(3), pp. 383-401 (1985)

113. Thijssen, J.J.J., Huisman, K.J.M., and Kort, P.M. “The effects of information on strategic investment and welfare”, *Economic Theory*, **28**(2), pp. 399-424 (2006)

114. Tran, V.D., Sibley, D.S., and Wilkie, S. “Second Mover Advantage and Entry Timing”, *The Journal of Industrial Economics*, **60**(3), pp. 517-535 (2012)

115. Vickers, J. “The evolution of market structure when there is a sequence of innovations”, *The Journal of Industrial Economics*, pp. 1-12 (1986)

116. Zhu, K. and Weyant, J.P. “Strategic Decisions of New Technology Adoption under Asymmetric Information: A Game-Theoretic Model*”, *Decision Sciences*, **34**(4), pp. 643-675 (2003)

FIGURE CAPTIONS

Figure 1. Elements of knowledge adoption strategy

Figure 2-Customer Segments of Technology Adoption

Figure 3.Model Framework

Figure 4 .The deterministic and robust model changes against the maximum violation probability

Figure 5-The deterministic and robust model changes against the deviation from the nominal data

Figure 6- The robust model has converged at the maximum violation probability 0.2 and deviation 10%

Figure 7--The deterministic model has converged at the maximum violation probability 0.2 and deviation 10%.

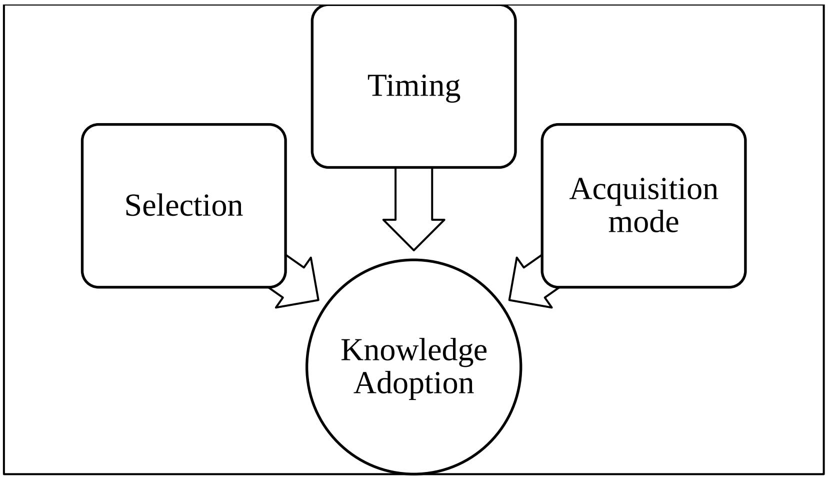

Figure 1. Elements of knowledge adoption strategy

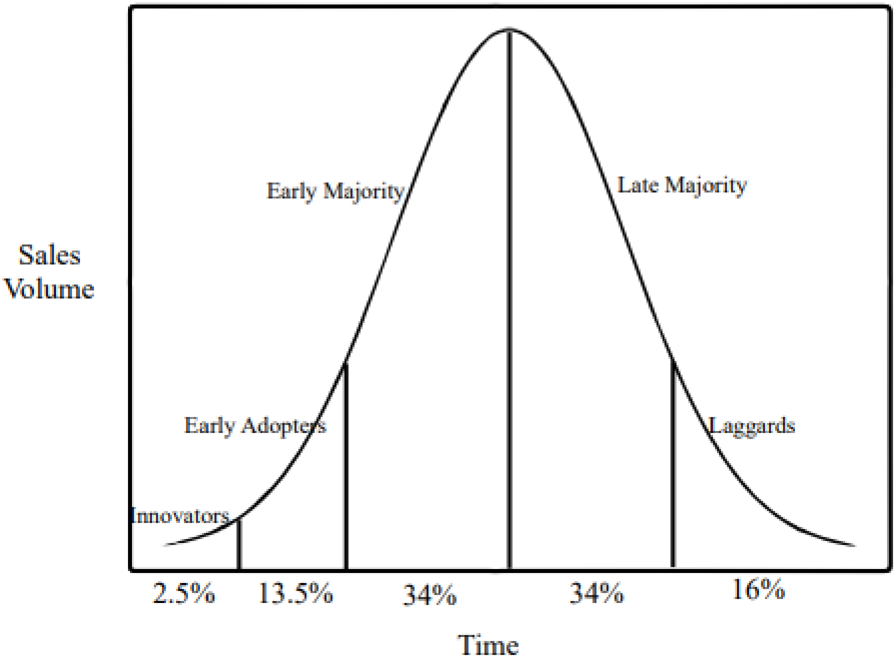

Figure 2-Customer Segments of Technology Adoption

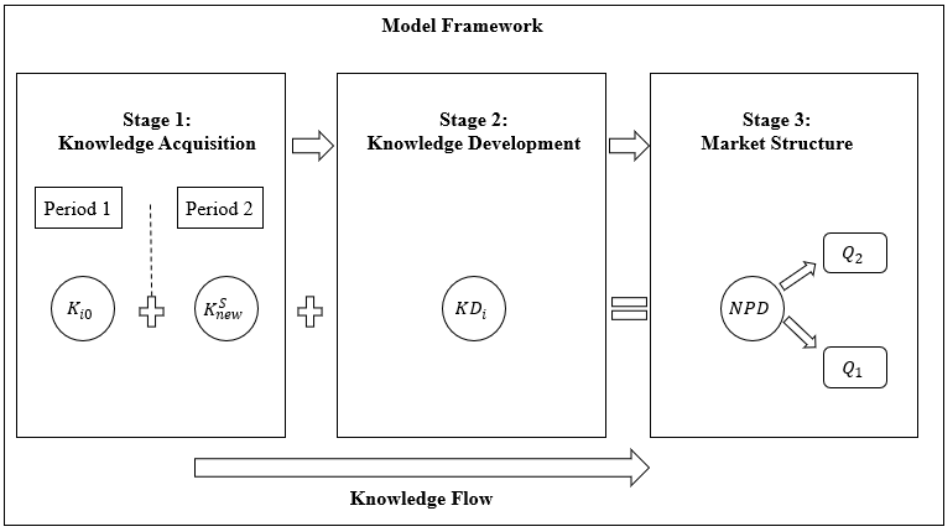

Figure 3-Model Framework

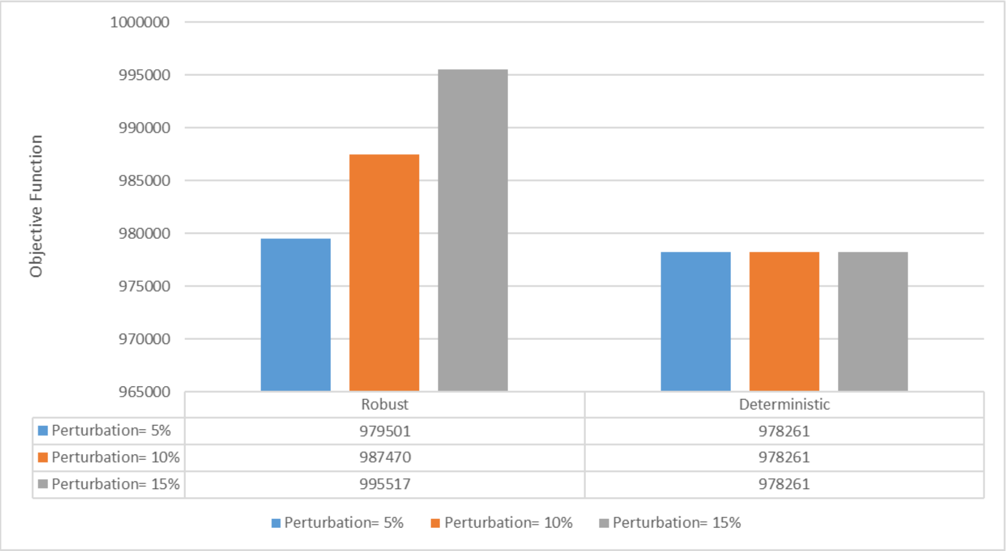

Figure 4 . The deterministic and robust model changes against the maximum violation probability

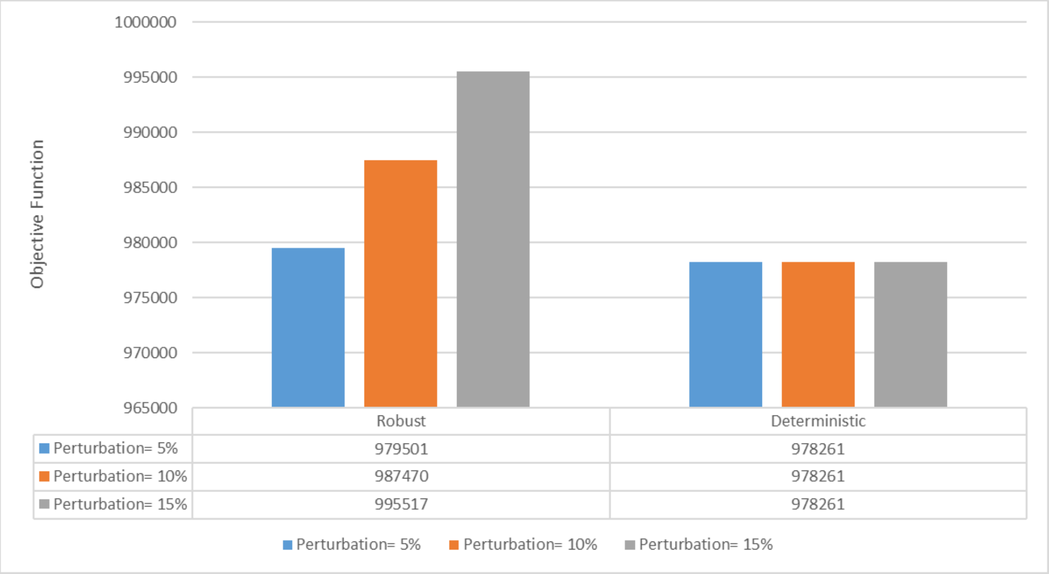

Figure 5-The deterministic and robust model changes against the deviation from the nominal data

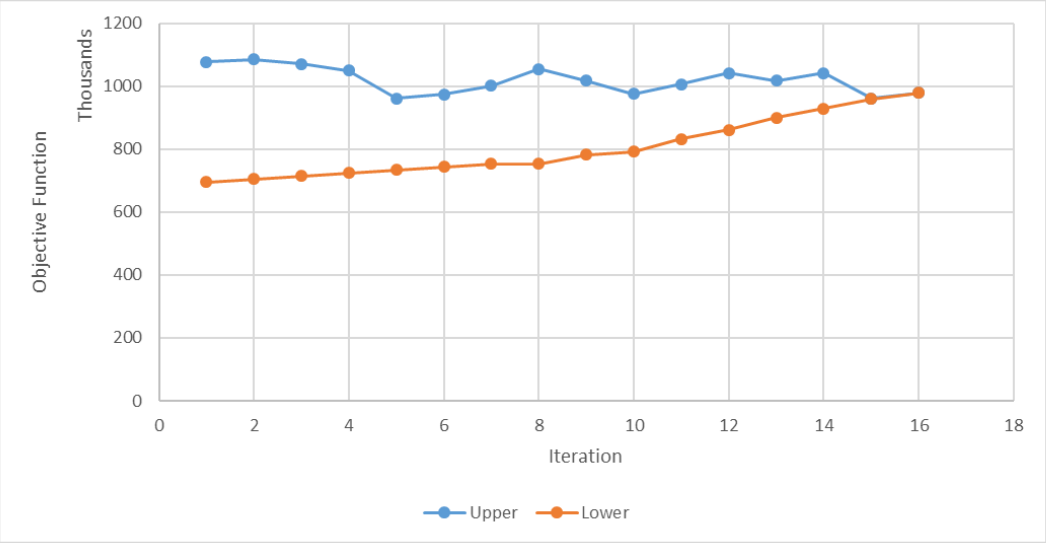

Figure 6- The robust model has converged at the maximum violation probability 0.2 and deviation 10%

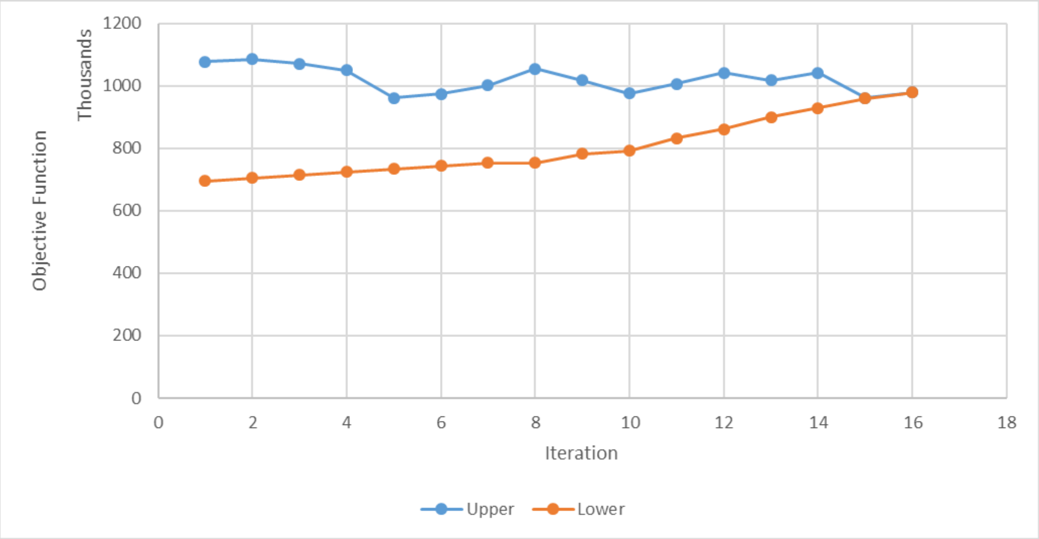

Figure 7-The deterministic model has converged at the maximum violation probability 0.2 and deviation 10%.

TABLE CAPTIONS

Table 1. Knowledge Selection Factors in literature

Knowledge Selection Factors		**Ref.**
internally	costs	[43-49]
	production capacity	
externally	marketing status	
	knowledge difficulty	
	Paybacks period	
	Risk of the knowledge	
	Flexibility	

Table 2.Advantages of being first or second mover

First mover advantage	**First mover disadvantage**	**Ref.**
Market reputation, Technological readership and Brand loyalty	Heavy R & D spending	[2, 50-55]
pre-emptible resources	Underdeveloped channels for procurement and distribution	
customer switching cost	The lack of Enabling technologies and complementary products	

Increasing returns	Uncertainty about customer needs

Table 3 . knowledge acquisition methods types

Subject	Knowledge acquisition method	Innovation type	Ref.
Licensing policies and R&D environments	fixed fee licensing, Royalty licensing, Fixed fee plus royalty licensing	cost-reducing innovation by a external firm	[56-59]
	royalty licensing, fixed-fee licensing, , two-part tariff contract, ad valorem royalties	cost-reducing innovation by a internal firm	[60, 61]
	fixed-fee and royalty licensing, fixed-fee plus royalty	Magnitude of the cost-reducting innovation.	[62-68]

Table 4. Knowledge Adoption Methods

Knowledge Adoption Strategy	Knowledge Adoption Method	Ref
Selection	Discounted Cash Flow	[69, 70]
	Cost/Benefit Analysis	[71-74]
	Net present value	[75-77]
	Return on Investment (ROI)	[78, 79]
	AHP	[80, 81]
	Critical Success Factors	[82, 83]
	Dynamic Programming	[84]
	Real Option models	[33, 85-88]
	Game Theory Models	[89-93]
Acquisition Mode	Discounted Cash Flow	[94]
	Cost/Benefit Analysis	[95]
	Net present value	[96]
	AHP	[97-99]
	Critical Success Factors	[100]
	Real Option models	[101]
	Game Theory Models	[1, 102-105]
Timing	Bayesian Decision Analysis	[29, 106]
	Real Option models	[107-110]
	Game Theory Models	[2, 41, 54, 85, 111-116]

Table 5. Model indexes, variables and parameters

	Simbol	Description
Index	$i, n \in \{1, 2\}$	Two competing firms
	$j, m \in \{1, 2\}$	Time periods of decision making

	$s \in \{1,2\}$	new technological knowledge level scenarios
Variable	K_{i2}^{s}	The technological knowledge amount of firm *i* at stage 2 under scenario *s*
	KD_i^s	KD in firm *i* under scenario s
	x_{ij}^{H}	If firm *i* in period *j* from the first stage acquire technological knowledge Simultaneously then 1; otherwise 0.
	x_{ij}^{T}	If firm *i* in period *j* from the first stage acquire technological knowledge Sequentially then 1; otherwise 0.
Parameter	K_{new}^{S}	Various scenarios for new technological knowledge
	K_{ij}	The technological knowledge level of firm *i* at time *j*
	π_y	Part y of the expected profit
	π	Expected profit
	γ	Technological knowledge converting coefficient to the marginal cost for each firm.
	c_i^s	The marginal cost of firm *i* under scenario *s*
	C_A	Total technological knowledge acquisition cost
	q_i	Production quantity of firm *i* on the market
	α	The probability of a low-quality technological knowledge
	β_i	Absorption capacity
	Z_i	loyal customers' valuation for firm *i*
	δ_i^s	the successful probability of firm *i* in the marketplace under scenario s
	p_s	probability of scenario s
	φ_i	technological knowledge valuation of firm *i* in the market
	I_0	Fixed cost of technological knowledge acquisition
	L	The advantage of learning
	r_{ij}	the risk of new technological knowledge selection in period j for firm i
	ω_i^s	The KD cost for firm i in the second stage under scenario s.
	B_i	The budget of firm *i*
	μ_i	Customers' valuation of the firm i if it is the only one to successfully develop a new product.

Table 6.The role of learning in acquiring technological knowledge

Situation	Learning	Firm i's Cost	Firm j's Cost
If both firms acquire technological knowledge in the same period.	No	I_0	I_0
If firm i acquires technological knowledge in the first period and firm j in the second period.	Yes	I_0	$(1-L)I_0$

Table 7.The objective function value of the robust model with 5% deviation from the nominal data

Pr=0.2	*978828*
Pr=0.15	*979293*
Pr=0.1	*979501*
	Definitive Model Object Function=*9782611*

Table 8.The objective function value of the robust model with 10% deviation from the nominal data

Pr=0.2	*987212*
Pr=0.15	*987423*
Pr=0.1	*987470*
	Definitive Model Object Function =*987261*

Table 9.The objective function value of the robust model with 15% deviation from the nominal data

Pr=0.2	*995364*
Pr=0.15	*995497*
Pr=0.1	*995517*
	Definitive Model Object Function =*978261*

Table 10 .Data of example

Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
K_{10}	*100*	r_{12}	*20*	K_{new}^{2}	*500*	ω_1^2	*3*
K_{20}	*80*	r_{21}	*60*	φ_1	*20*	ω_2^1	*6*
β_1	*0.593*	r_{22}	*30*	φ_2	*20*	ω_2^2	*4*
β_2	*0.375*	B_1	*1000*	Z_1	*100*	δ_1^1	*0.33*
L	*0.3*	B_2	*1000*	Z_2	*100*	δ_1^2	*0.5*
I_0	*300*	p_1	*0.5*	μ_1	*10*	δ_2^1	*0.33*
V	*100*	p_2	*0.5*	μ_2	*10*	δ_2^2	*0.5*
r_{11}	*50*	K_{new}^{1}	*200*	ω_1^1	*4*		

Table 11.First stage variables

	Firm 1		**Firm 2**	
	First period	Second period	First period	Second period
Simultaneous selection (x_i^H)	*0*	*0*	*0*	*0*
Sequential selection (x_i^T)	*0*	*1*	*1*	*0*

Table 12. Second stage variables

	First scenario (Low level of new technological knowledge)	**second scenario (high level of new technological knowledge)**
The amount of first - firm technological KD	*175*	*233.333*
The amount of second- firm technological KD	*116.667*	*175*
Technological knowledge level of the first firm at the end of the second stage	*393.6*	*629.833*
Technological knowledge level of the second firm at the end of the second stage	*271.667*	*442.5*

Table 13.Market share

	First scenario **(Low level of new technological knowledge)**	**Second scenario** **(high level of new technological knowledge)**
The production cost of the first firm(follower)	0.0025γ	0.0016γ
The production cost of the second firm (leader)	0.0037γ	0.0023γ
Market Share of the first firm(follower)	$\frac{\theta - 0.001\gamma}{4}$	$\frac{\theta - 0.002\gamma}{4}$
Market Share of the second firm(leader)	$\frac{\theta - 0.0099\gamma}{2}$	$\frac{\theta - 0.0062\gamma}{2}$

Table 14.Winner in the market

Parameter value	**Winner**	
$\theta \geq 0.02\gamma$	First scenario	Second firm(leader)
	second scenario	
$0.012\gamma \leq \theta < 0.02\gamma$	First scenario	first firm(follower)
	second scenario	Second firm(leader)
$\theta < 0.012\gamma$	First scenario	first firm(follower)
	second scenario	

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