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# DOES IT SYNERGY MATTER IN IT PORTFOLIO SELECTION?

*Completed Research Paper*

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## **Abstract**

*This paper proposes a framework of IT portfolio selection and examines the impact of IT synergy on a firm's IT portfolio selection. IT resources can be distinguished from other forms of resources by their great potential of enhancing synergy between IT units. Based on prior discussion on types of IT synergy, we classify IT synergy into three types and examine the effects of the different types of IT synergy on the IT portfolio selection. We found that firms of moderate and high risk tolerance are likely to obtain a superior IT portfolio by enhancing IT synergy, whereas firms of low risk tolerance may not benefit from enhancement of IT synergy.*

**Keywords:** IT Portfolio Selection, IT investment allocation, efficient frontier

## **Introduction**

This study aims to propose how rational firms will use IT synergy to optimize their IT portfolio. For financial investors, Markowitz portfolio selection theory proposes how rational investors will diversify their investment to achieve an optimal portfolio. Investors can use information about diversification of their investment portfolio to estimate and reduce the portfolio risk when they expand their view from a level of individual units to a portfolio level. This study extends the financial portfolio selection theory to the domain of IT portfolio selection. We argue that, when a firm extends their view from a level of individual IT investment units to a portfolio level, the firm can use IT synergy as well as diversification to optimize its IT portfolio.

IT investments in a firm have continued to increase. Estimated 50 percent of U.S. capital investment is for IT (Lucas, 2005, p. 113). The size of IT spending in a firm today has become huge and the decisions of the IT investment are critical for the business performance of the firm. According to our survey with CIOs (Chief Information Officers) in three Fortune 100 firms, their annual IT spending ranges from tens of million dollars to one billion dollars. Along with this trend of growing IT investment, the role of the CIO who takes charge of IT investments has become increasingly important. However, there are few widely accepted methodologies with which IT managers can optimize their IT resources.

Weill and Vitale (2002) define IT portfolio of a firm as “its total investment in computing and communication technology.” Jeffery and Leliveld (2004) define IT portfolio management as “managing IT as a portfolio of assets similar to a financial portfolio and striving to improve the performance of the portfolio by balancing risk and return.” Maizlish and Handler (2005) classify the IT portfolio management problem into three different levels: the IT discovery portfolio, the IT project portfolio, and the IT asset portfolio. The decision unit in our study can be any IT investment unit, but the main focus of our study lies on the allocation problem that matters for CIOs or senior IT managers. For example, a CIO of the firm may have to allocate its total IT budget to IT organizations for individual business units in a multi-business firm, or for individual functional departments such as the marketing department and the operation department.

We argue that the greater potential of synergy enhancement between IT investment units differentiates IT portfolio selection from the financial portfolio selection. Holding multiple financial products does not create additional return, whereas holding multiple IT resources may enable a firm to earn additional return from its IT investment. The synergy and diversification have been discussed in strategy literature, particularly in the multi-business context (Tanriverdi and Venkatraman, 2005; Rumelt, 1982; Amihud and Lev, 1981; Christensen and Montgomery, 1981; Palepu, 1985; Robins and Wiersema, 1995; Farjoun, 1998; Miller, 2004). However, there have been not enough studies of synergy in the domain of IT investment. The unique characteristics of IT resources other than non-IT resources motivated us to study IT synergy.

In this paper, we develop a framework of IT portfolio selection, and provides the model of IT portfolio selection with which decision makers in a firm can attain optimal IT portfolio from their IT investment. In addition, we examine the effect of IT synergy on a firm’s IT portfolio selection using the framework.

## **Theoretical Background**

### ***Markowitz’s Portfolio Selection Theory***

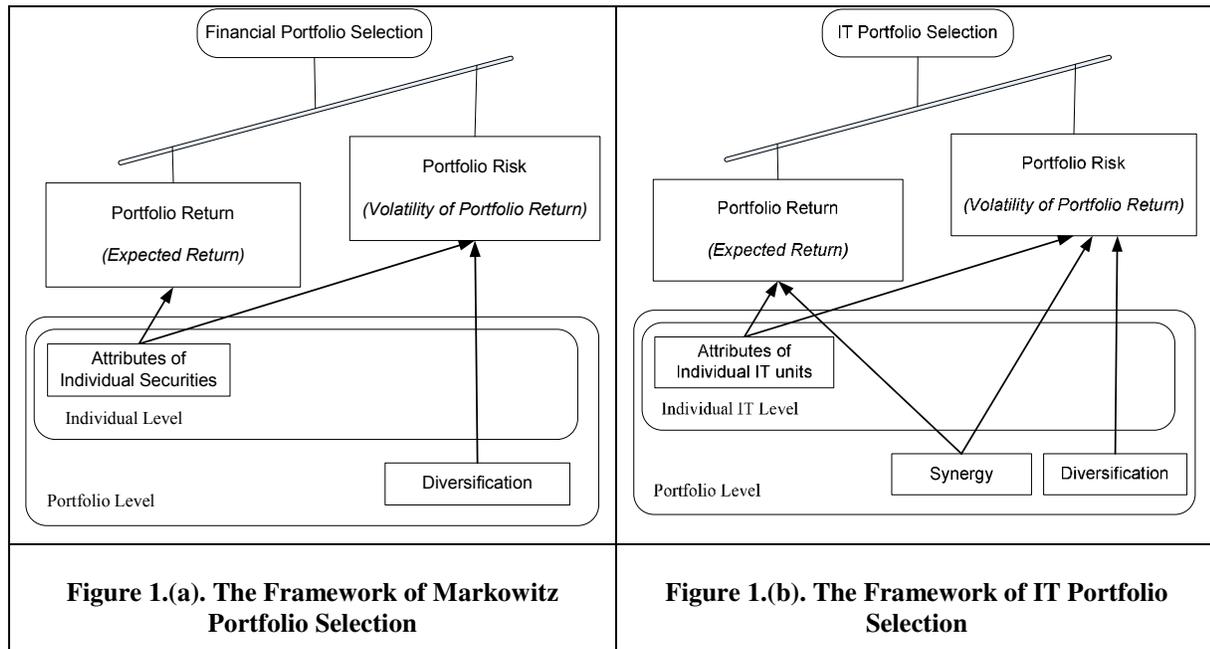
Financial theories have been applied in strategic planning of the firm. Meyers (1984) argues that finance theory must be extended in order to bring financial and strategic analysis together. This paper extends the Markowitz theory to apply it to IT portfolio selection problems. In Markowitz’s portfolio selection theory, an investor’s problem is viewed as a problem of balancing return and risk. The main benefit of using Markowitz’s portfolio selection theory in financial investment is that an investor can reduce portfolio risk simply by holding multiple securities that are not perfectly correlated (Markowitz, 1991). This benefit acts as a strong incentive for investors to apply the portfolio selection theory.

The portfolio selection theory has been most actively studied in the field of finance where various portfolio selection models have been developed. An essence of investment in the portfolio selection theories is to balance return and risk. This principle of investment can be applied to both financial portfolio selection and IT portfolio selection.

However, there are major differences between IT portfolio selection and financial portfolio selection. This gap addresses the necessity of developing models for IT portfolio selection that is distinguished from financial portfolio selection models.

Holding multiple financial units does not create any additional return. The return from multiple financial investments is equal to the sum of returns of individual investments. However, the return of IT portfolio may not be equal to the sum of returns of individual IT investments because synergies between IT units can be created. For example, when two IT project are implemented or maintained together, a firm may be able to save costs or create additional values through integration. Figure 1 (a) and (b) illustrate the difference between Markowitz portfolio selection and IT portfolio selection. In financial portfolio selection, the portfolio management means the use of diversification to reduce portfolio risk. However, we argue that IT portfolio management implies the use of IT synergy as well as the use of diversification, where IT synergy affects both portfolio return and portfolio risk.

Reselling financial products is, in general, not too difficult even after an investor purchases them because the market value of financial products does not change depending on the owner of the financial products. However, after an organization invests in an IT project or IT systems, the value of the IT systems to the organization is much greater than the value of the IT systems to other organizations or a market value. The intricacy in rolling decisions of IT investment back would lead to the greater impact of the investment risk in IT portfolio selection. Thus, selecting IT portfolio should weigh portfolio risk more highly than investment in financial products. To reflect the greater importance of risk in IT portfolio selection, we understand IT portfolio selection as a problem of balancing return and risk.



**Synergy**

Synergy refers to additional return when firms can achieve from multiple investment units, which cannot be attained from stand-alone individual units. Synergy between multiple investment units has been actively discussed in the corporate strategy and finance literature. It is argued that the wealth gain is attributed to the utilization of resources resulting in different types of synergies (Eckbo, 1983; Bradley et al., 1983). Economies of scope enable a firm to share or utilize related inputs, which enhance synergy (Tece, 1980, 1982; Willig, 1978).

The main concern of prior studies in the corporate strategy literature is whether a corporate should diversify in its businesses. It is assumed that synergism is given to firms depending on their corporate structure and diversification strategies in this literature. However, this assumption needs to be reexamined because some empirical studies showed that managers overestimate their ability to obtain synergies from diversification (Miller, 2004). To our knowledge, few studies tried to answer for whether a firm has an incentive to enhance a certain types of synergy by investigating their effect on portfolio return and risk. Moreover, in the domain of IT investment of the firm, synergy

enhancement can be an option for CIOs or IT managers because information technologies have enormous potential of synergy enhancement. Thus, the discussion of synergy in this paper has a different aim from the studies of the corporate diversification strategy. We view IT synergy as a choice of a firm to achieve an optimal portfolio.

For IT resources, two types of synergies, sub-additive cost and super-additive value synergies, have been discussed (Tanriverdi, 2005, 2006). First, sub-additive cost synergy has been explained by the economics of scope that can be attained through diversification (Willing, 1978; Panzar and Willing, 1981; Teece, 1980, 1982). The synergistic economies arise from inputs that are shared by related businesses, and the synergistic benefits are distinguished from vertical economies and financial economies (Hill et al., 1987). Resource relatedness refers to the use of common resources across units. According to the resource-based view of the firm, the use of common factors of production across units in diversification creates synergies, which is sub-additive production cost synergies (Farjoun, 1998; Robins and Wiersema, 1995; Tanriverdi, 2006). Second, the super-additive value synergies can be derived from Edgeworth complementarities, which can be described as 'doing more of one thing increases the returns to do more of another' (Milgrom and Roberts, 1995). Resource complementary is a major source of cross-unit synergy (Tanriverdi and Venkatraman, 2005). According to the economic theory of complementarities (Milgrom and Roberts, 1995), a set of resource is complementary when the return to a resource varies in the levels of returns to the other resources. A complementary set of resources creates super-additive value synergies.

### ***Portfolio Risk***

There is widespread recognition that risk management in IT investment is critical after firms experience such a high failure rate in IT investments. The need for risk management in IT investment has motivated researchers to propose various schemes. Real option analysis has been applied to IT investment decisions, which provide a method of risk management by considering option value of individual IT investment unit (Mittendorf 2004, Benaroch 2002, Benaroch et al. 2006). Value-at-Risk (VaR) analysis is another approach of risk management, in which risk is redefined and only negative direction of volatility is considered. VaR is a threshold value that investors specifies for their investment portfolio, and it can be a measure of risk. In this study, we adopt the efficient frontier as a tool of risk management. The benefit of the efficient frontier is to enable firms to choose an optimal IT portfolio depending on their risk tolerance or risk appetite. Thus, the efficient frontier allows executive-level managers to make decisions for their trade-off between the portfolio return and the portfolio risk.

Mixed results about the relationship between IT investments and firm performance have been reported in empirical studies. A possible reason of the mixed results is that most studies ignore risk but measure the performance in terms of just return (Tanriverdi and Ruefli, 2004). Because both return and risk are major dimensions of performance of an investment (Bettis and Mahajan, 1985), this study develops the framework of IT portfolio selection in which both return and risk are conceptualized as sub-objectives. In finance, portfolio risk is defined as the standard deviation of the portfolio's return (Markowitz, 1952). In the management literature, four definitions of risk have been used: (1) size of loss, (2) probability, (3) variance (standard deviation) of returns, and (4) lack of information (Tanriverdi and Ruefli, 2004). Though the probability and size of loss is most widely used by practitioners, we define portfolio risk as standard deviation of portfolio return because it has the strongest mathematical foundations compared to other definitions and we use an analytic approach in this study.

## **IT Resources and IT Synergy**

Similar to general concept of synergy, IT synergy refers to additional return that a firm can achieve from multiple IT investment units, which cannot be obtained from stand-alone individual units. We argue that IT resources have unique characteristics that bring greater potential of enhancing synergy than non-IT resources. In this section, we intend to justify this argument by discussing why IT resources are more significant sources of synergy than non-IT ones. This discussion will add importance of IT synergy in IT portfolio management.

### ***Characteristics of IT resources***

We address three unique characteristics of IT resources that is related to the great potential of synergy enhancement. First, IT resources can be used remotely. Most IT services are provided and shared through networks, and geographic constraints in using resources are minimized. Computer machines and software programs may not need to be moved or re-installed to be used in a specific place, and developers can work remotely through computer networks. Second, IT resources can be used by multiple users simultaneously. As long as the traffic limit is not

exceeded, many IT resources can be used whenever they are needed by many users. These first two features make IT resources much more sharable between different IT investment units and create greater synergy than non-IT resources. Thirdly, the integration between heterogeneous IT systems enables firms to share business processes and exchange data, which enhance complementarities between IT components. The data provided by an information system makes other systems more valuable. Integrated business processes between multiple information systems can create additional sets of data and higher quality information.

<b>Table 1. Three Types of IT Synergies</b>			
Types	Sub-additive cost IT synergy ( <i>c-type</i> synergy)	One-way Super-additive Value IT synergy ( <i>ov-type</i> synergy)	Two-way Super-additive Value IT synergy ( <i>tv-type</i> synergy)
Definition	Additional value created when there is sharing of common IT resources between two IT units.	Additional values created by the relationship between two IT units (A and B), where the value of one IT unit (A) is influenced by the value of the other IT unit (B), but the value of B is not influenced by the value of A.	Additional value created by the relationship between two IT units, where the return rate of one IT unit is affected by the value of the other IT unit.
Key characteristics of IT resource related to the synergy	Capability of the remote and simultaneous use	Heavy dependence of IT applications on IT infrastructure;  Applicability across a wide range of businesses and industries	Integration;  Applicability across a wide range of businesses and industries
Theoretical orientation	Economies of scope (Willing, 1978; Panzar and Willing, 1981; Teece, 1980, 1982);  Relatedness of resources (Farjoun, 1998; Robins and Wiersema, 1995; Tinriverdi, 2006)	Resource Complementarities (Zhu, 2004)	Complementarities between IT resources (Milgrom and Roberts, 1990, 1995; Tanriverdi and Venkatraman, 2005)
Examples	IT machines, IT human resources, and other IT resources can be shared across different business units or functional groups.	The performance of software programs depends on hardware and networks on which the programs are running.	Marketing Information Systems, New Product Development Systems and Customer Service Systems can create additional information and value by exchanging data and business processes.

**The Uncertainty of IT Resources**

Resources of a firm can be anything that is thought of as a strength and weakness of the given firm (Wernerfelt, 1984). According to RBV (Resource-Based View) of the firm, resources of a firm enable the firm to achieve competitive advantage, and to drive toward superior long-term performance (Barney 1991; Penrose 1959; Wernerfelt 1984). Using the criteria of strategic resources in RBV– valuable, rare, in-imitable, and non-substitutable (Barney, 1991), we can argue that a main role of the CIO of the firm is to develop strategic IT resources from IT investment, by making their IT resources valuable, rare, in-imitable, and non-substitutable. When the IT resources of

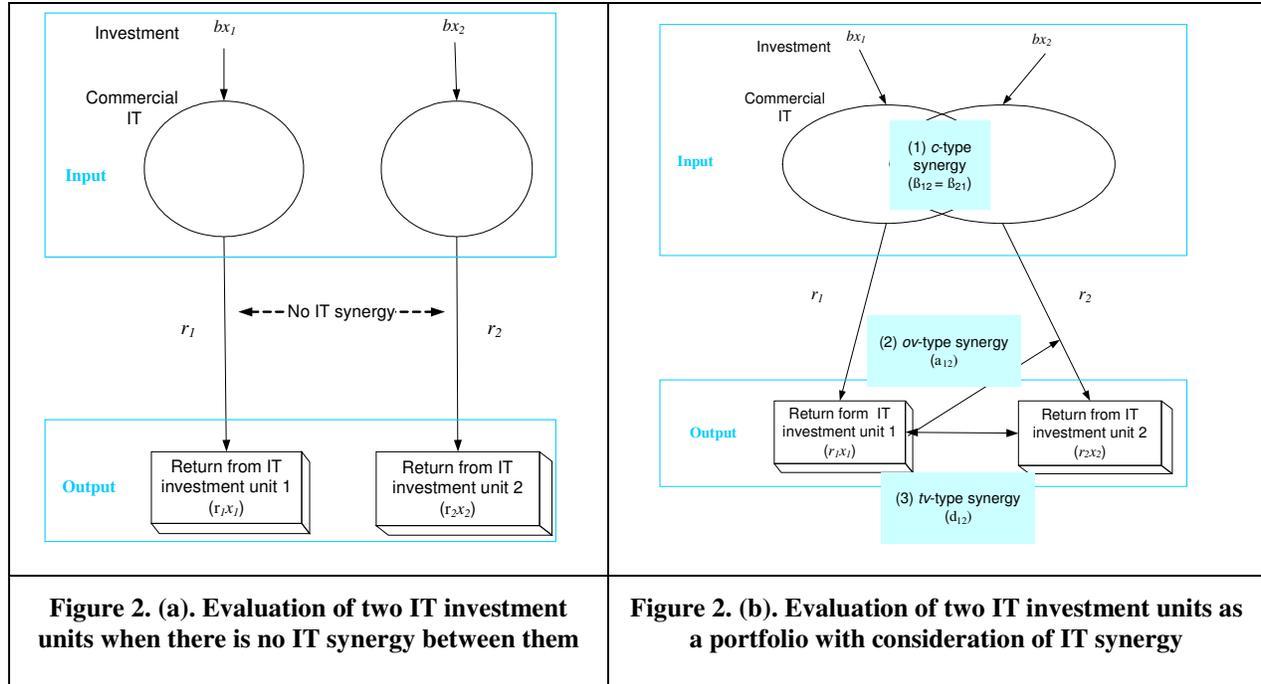
the firm fit well with unique needs of the organization, the firm is able to achieve maximum value of the IT resources.

Here, we need to distinguish the existing IT resource, which is used as the input of an IT investment, and the prospect IT resource, which is the output of an IT investment. We assume that there is no uncertainty in using existing IT resources because firms have used the existing IT resources and are likely to know their values. However, the value of the prospective IT resource is uncertain; thus, there is uncertainty in the return of the IT investment.

### Three types of IT synergy

Figure 2. (a) and (b) compare the two-unit portfolios: one is when two IT investment units are evaluated without any synergy; the other is when there is synergy. As we discussed earlier, by viewing IT units aggregately, a firm is able to take synergies into consideration in their IT portfolio selection. We classify IT synergies into three types: the sub-additive cost IT synergy (*c*-type synergy); the two-way super-additive value IT synergy (*tv*-type synergy); and the one-way super-additive value IT synergy (*ov*-type synergy). Table 1 summarizes the three types. To develop models of the three types of IT synergies, we use the following settings and notations.

- $x_i$ : the proportion of IT investment unit  $i$  out of the total IT investment ( $i = 1, 2; 0 < x_1, x_2 < 1; x_1 + x_2 = 1$ )
- $r_i$ : the expected return on investment (ROI) of IT investment unit  $i$  when the two IT units are evaluated without any synergy
- $\alpha_{ij}$ : the marginal increase (decrease) of the ROI of the IT investment unit  $j$  over the marginal increase (decrease) of the value of IT investment  $i$  ( $\alpha_{ij} > 0$ )
- $\beta_{ij}$ : the maximum percentage of the IT resource share between IT investment unit  $i$  and  $j$ , out of the sum of required IT resources by the two investments individually ( $\beta_{ij} = \beta_{ji} > 0$ )
- $\delta_{ij}$ : the maximum percentage of additional value created when the two IT investment units are selected over the sum of stand-alone returns of individual IT resources ( $\delta_{ij} = \delta_{ji} > 0$ )



### The Sub-additive Cost IT Synergy

The sub-additive cost IT synergy (*c*-type synergy) refers to additional cost saving when there is sharing of common IT resources between two IT units. A condition of sub-additive cost synergy is  $Cost(A+B) < Cost(A) + Cost(B)$

(Teece, 1982). Examples of this type of synergy can easily be found. Hardware, software, network systems, IT human resources, and other IT resources can be shared across different business units or functional groups. In our model, we assume that the firm can estimate the maximum percent of IT resources that can be shared by two IT investment units.

In our model, we assume that the maximum percentage of IT resource shared between two IT investment units can be estimated by IT experts in the firm. The additional portfolio return will be the amount that the firm can save in sharing existing IT resources. The amount will be  $\beta_{12} En(x_1, x_2)$ , where  $En(x_1, x_2)$  refers to an entropy function of which value is maximized when the investment is most diversified, here  $x_1 = x_2$ . A widely-used entropy function is Jacquemin-Berry entropy measure  $\sum_{i \in j} P_i^j \ln(1/P_i^j)$ , where  $P_i^j$  is the share of the segment  $i$  of group  $j$  in total

(Palepu, 1985). Then, when the sub-additive cost synergy exists and other types of IT synergy do not exist, the portfolio return,  $RT$ , will be:

$$RT = r_1 x_1 + r_2 x_2 + \beta_{12} En(x_1, x_2), \quad (1)$$

where  $\beta_{12} = \beta_{21}$ . We define portfolio risk as the standard deviation of portfolio return, as it is defined in finance literature. The sub-additive cost synergy appears not to affect portfolio risk because the additional return is nothing to do with any ROI (Return on Investment) term that has uncertainty. The variance of portfolio return with the sub-additive cost synergy is the same as that of portfolio return without the synergy. The portfolio Risk,  $RK$ , will be:

$$\begin{aligned} RK &= [Var(r_1 x_1 + r_2 x_2 + \beta_{12} En(x_1, x_2))]^{1/2} \\ &= [Var(r_1 x_1 + r_2 x_2)]^{1/2} \end{aligned} \quad (2)$$

### The One-way Super-additive Value IT Synergy

The super-additive value IT synergy refers to additional value created by the complementary relationship between the two IT units. The condition of super-additive value synergy is  $Value(A+B) > Value(A) + Value(B)$  (Davis and Thomas, 1993). In this study, we distinguish one-way super-additive value IT synergy from two-way super-additive value IT synergy.

The one-way super-additive IT synergy (*ov-type* synergy) occurs when, between two IT investment units, the intrinsic value of the first IT investment unit affects the value of the second unit but is not affected by the value of the second unit. Zhu (2004) explains the effect of IT infrastructure with complementarities. We argue that the complementarities of IT infrastructure are different from the complementarities in which both units are mutually influenced. IT infrastructure affects the value of IT applications but it is hardly influenced by the value of IT applications. For example, performance of most IT systems is influenced by performance of hardware and networks. As the performance of hardware and networks increase, productivity of IT applications will increase. If we consider a business unit whose operations heavily depend on various IT systems and IT machines, it is reasonable to think that the value of the IT infrastructure is positively related to the IT value of the business unit.

We assume that, in the relationship between IT investment unit  $i$  and IT investment unit  $j$  ( $i, j = 1, 2, i \neq j$ ), the marginal increase (decrease) of the ROI of IT investment unit  $j$  over the marginal increase (decrease) of the value of IT investment  $i$ ,  $\alpha_{ij}$ , can be estimated in the range of  $x_i$  and  $x_j$  specified by the firm. We assume  $\alpha_{ij} \geq 0$  because IT managers would not integrate the two IT units in case of  $\alpha_{ij} < 0$ . When IT investment unit 1 has *ov-type* synergy on the IT unit 2, the firm will obtain the additional return  $\alpha_{12}(r_1 x_1)x_2$ .

Then, when *ov-type* synergy exists without any other types of IT synergies, the portfolio return of IT investment unit 1 and 2 will be:

$$RT = r_1 x_1 + r_2 x_2 + \alpha_{12}(r_1 x_1)x_2 \quad (3)$$

In calculating portfolio risk, we assume that the firm can collect information about correlation between the ROI of two investment units,  $\rho_{12}$ , and standard deviation of the ROIs,  $\sigma_1$  and  $\sigma_2$ . Then, when the super-additive value synergy exists, the portfolio risk will be:

$$RK = [Var(r_1x_1 + r_2x_2 + \alpha_{12}(r_1x_1)x_2)]^{1/2} \quad (4)$$

### The Two-way Super-additive Value IT Synergy

The two-way super-additive value IT synergy (*tv*-type synergy) occurs when the two IT units are mutually beneficial. Integration between different IT systems is one of main sources. For example, marketing systems and new product development systems of a firm can exchange data about customers and their preference on quality attributes of a product. The data exchange can help the marketing systems do marketing research and find customers, and help new product development systems in designing new products that customers actually need.

We assume that a firm can estimate the ratio between maximum additional return created from *tv*-type synergy and the sum of the stand-alone returns of the two IT investment units. With this assumption, we formulate the additional return from *tv*-type synergy as follows: The additional portfolio return will be the amount that the firm can attain the additional value and the amount will be  $\delta_{12}(r_1x_1 + r_2x_2)En(r_1x_1, r_2x_2)$ ,  $\delta_{21} = \delta_{12}$ . Then, when *tv*-type synergy exists and other types of IT synergies do not exist, the portfolio return will be:

$$RT = r_1x_1 + r_2x_2 + \delta_{12}(r_1x_1 + r_2x_2)En(r_1x_1, r_2x_2) \quad (5)$$

This type of IT synergy appears to change portfolio return because the additional term includes the ROIs that have uncertainty.

$$RK = [Var(r_1x_1 + r_2x_2 + \delta_{12}(r_1x_1 + r_2x_2)En(r_1x_1, r_2x_2))]^{1/2} \quad (6)$$

## IT Portfolio Selection Model

### Research Problem and IT Efficient Frontier

We intend to solve the problem of IT investment allocation that CIOs or senior IT managers in a large-size firm face. IT organizations in a firm would have IT budget and the CIO needs to allocate their IT budget into multiple IT investment units for strategic IT spending. For example, a CIO in a firm needs to allocate a certain IT budget for different functional divisions, such as operation, marketing and IT infrastructure. A CIO in a multi-business firm may need to allocate IT budget to different business units. Individual functional groups or business units may want to get IT budget for their unit as much as possible to implement IT projects and initiatives proposed by them. The IT investment unit, in our model, is a general unit. It refers to any decision making units that CIOs or IT decision makers may have. Our model can be applied to a problem of allocating IT budget for multiple business units, for different types of IT, such as hardware, software and network, for different functional groups such as IT for marketing group, IT for operation, and IT for customer service group.

To examine the effects of IT synergy on IT portfolio selection of the firm, we apply the Markowitz's mean-variance efficient frontier. The efficient frontier is a visual presentation of the balance between portfolio return and risk. We believe that the efficient frontier is a useful tool for CIOs because IT portfolio is an investment for them and every investment can be viewed as a problem of balancing return and risk. Similar to efficient frontier for security portfolio selection (Kroll, Levy, and Markowitz, 1984), IT efficient frontier can be defined as the intersection of the set of portfolios with minimum risk and the set of IT portfolios with maximum return. However, we extend the original efficient frontier by incorporating the construct of IT synergy. The difference of IT efficient frontier from the Markowitz's mean-variance efficient frontier is that the expected portfolio return is the function of synergies as well as individual units' return. With the additional factors of expected portfolio return, the portfolio risk will be changed correspondingly because portfolio risk is defined as the standard deviation of portfolio return.

The objective of the CIO for the problem of IT investment allocation is to balance two sub-objectives: to maximize portfolio return versus to minimize portfolio risk. Portfolio return is determined by the return of individual IT

investment units and synergies. The synergies include *c-*, *ov-* and *tv-*type synergies. We assume that *ov-* and *tv-*type synergy between the two IT units are exclusive. It means that there cannot be both *ov-* and *tv-*type synergy between the two units. In our model, we use synergy measured only between two units because practically it is very difficult to measure additional return created from interactions from more than three IT units. The portfolio return,  $RT$ , can be represented as:

$$RT = RT(\text{expected returns of individual IT units, synergies})$$

The risk of an IT portfolio can be defined as the standard deviation of the portfolio return, which, conceptually, refers to the degree of uncertainty of the return. Thus, the portfolio risk,  $RK$ , can be represented as:

$$RK = [\text{Var}(RT(\text{expected returns of individual IT units, synergies}))]^{1/2}$$

For example, the IT efficient frontier consists of two IT investment units, as illustrated in Figure 1. (b), can be plotted with the following formulas

$$RT = r_1 bx_1 + r_2 bx_2 + \alpha_{12}(r_1 bx_1)x_2 + \beta_{12}bEn(x_1, x_2) + \delta_{12}b(r_1x_1 + r_2x_2)En(r_1x_1, r_2x_2) \quad (7)$$

$$RK = [\text{Var}(RT)]^{1/2}$$

### Decision Variables

The decision variable in the model is the proportion of investment for each IT investment units. The IT investment unit can be any level that CIOs or senior manager IT managers would allocate their IT budget. The amount of dollars in each IT investment unit is normalized and  $x_i$  refers to the ratio of amount of dollars to the total amount of IT investment. The range of  $x_i$  will be ranged from zero to one.

### Constraints

Constraints in the IT portfolio optimization model should address the unique characteristics of the IT organization of the firm. These constraints include budget constraints, logical constraints (Liesio et al. 2008), positioning constraints (Liesio et al. 2008), threshold constraints (Kleinmuntz, 2007).

### The IT Portfolio Selection Model

The optimization problem of balancing between return and risk can be formulated to three optimization models and the three models will produce an identical efficient frontier. The first model is to maximize portfolio return with constraints of portfolio risk. The second model is to minimize portfolio risk subject to a certain level of portfolio return. The third model has the objective function in which the two sub-objectives are linearly combined.

Model 1: (8)

*Maximize*  $RT$

*Subject to*  $RK \leq RK_0$

(other constraints)

, where  $RK_0$  refers to the maximum level of portfolio risk that the firm can tolerance

Model 2: (9)

*Minimize*  $RK$

*Subject to*  $RT \geq RT_0$

(other constraints)

, where  $RT_0$  refers to the minimum level of portfolio return that the firm must achieve

Model 3: (10)

$$\text{Maximize } RT + w(RK - RK_0)$$

Subject to (other constraints)

, where  $w$  is the parameter that represent weight attached to portfolio risk compared to portfolio return. For the IT portfolio that consists of  $n$  IT investment units, the portfolio return and the portfolio risk are defined as:

$$RT = \sum_{i=1}^n r_i x_i + \sum_{i=1}^n \sum_{j=1}^n \alpha_{ij} (r_i x_i) x_j$$

$$+ \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \beta_{ij} (r_i x_i) x_j \text{En}(x_i, x_j) + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \delta_{ij} (r_i x_i + r_j x_j) \text{En}(r_i x_i, r_j x_j)$$

$$RK = [\text{Var}(RT)]^{1/2}$$
(11)

The bi-criteria linear programming in Model 3 can be theoretically explained by Lagrange relaxation of the optimization problem of maximizing portfolio return with the constraint of not taking a certain level of risk. Then  $w$  would be a Lagrange multiplier that represents the shadow price of the risk constraints. If we let  $L = RT + w(RK - RK_0)$ , then  $\partial RT / \partial RK = w$ , because  $\partial L / \partial RK = w$  and  $\partial L / \partial RT = 1$ . Therefore, the Lagrange multiplier  $w$  refers to the marginal increase of portfolio return over marginal increase of portfolio risk at a portfolio risk.

### The Effects of IT Synergy on IT Portfolio Selection: A Computational Study

In this section, we examine the effects of the three types of IT synergies on a firm’s portfolio selection, using the model we developed in prior sections. In many situations, enhancement of IT synergy is not for free, the enhancement will be an option of a firm. Then, firms will decide to enhance IT synergy only when they have an incentive to do. Firms can raise a question: do synergies always offer a better portfolio? If not, under what conditions synergies enable firms to have superior portfolios or inferior ones. By observing changes in the efficient frontier of the firm, we intend to discuss about those questions.

We consider an IT portfolio for two IT investment units as described in Figure 2. (b). Since our model uses data of synergies and correlations measured between two IT units, not data measured among more than three IT units, it is meaningful to investigate the efficient frontier for two IT units. The result of the efficient set for two units can be applied to the efficient set for many IT units. The main usage of the efficient frontier is to know feasible portfolios and the efficient set. We can obtain feasible portfolios and an efficient frontier for many units by combining feasible areas plotted by pairs of IT units, pairs of an IT unit and an aggregate IT unit, or pairs of aggregate IT units. We consider the two-unit portfolio with the following assumptions: (1) a firm has two IT investment units and needs to allocate IT budget for the two units; (2) the first IT investment unit is characterized as low-return and low-risk and the second unit as high-return and high-risk.

The computational experiment requires specification of project data. We assume that the data in Table 2 is the return on investment (ROI) of the two IT investment units that the firm collected without any enhancement of IT synergy. The ROIs are estimated for four scenarios - Scenario I, II, III, and IV - of which probability is 25% respectively. Using data in Table 2, we can calculate the expected ROI of unit 1, 2.0, the expected ROI of unit 2, 3.5, the standard variation of the ROI of unit 1, 0.71, the standard variation of the ROI of unit 2, 1.27, and the covariance, 0.58.

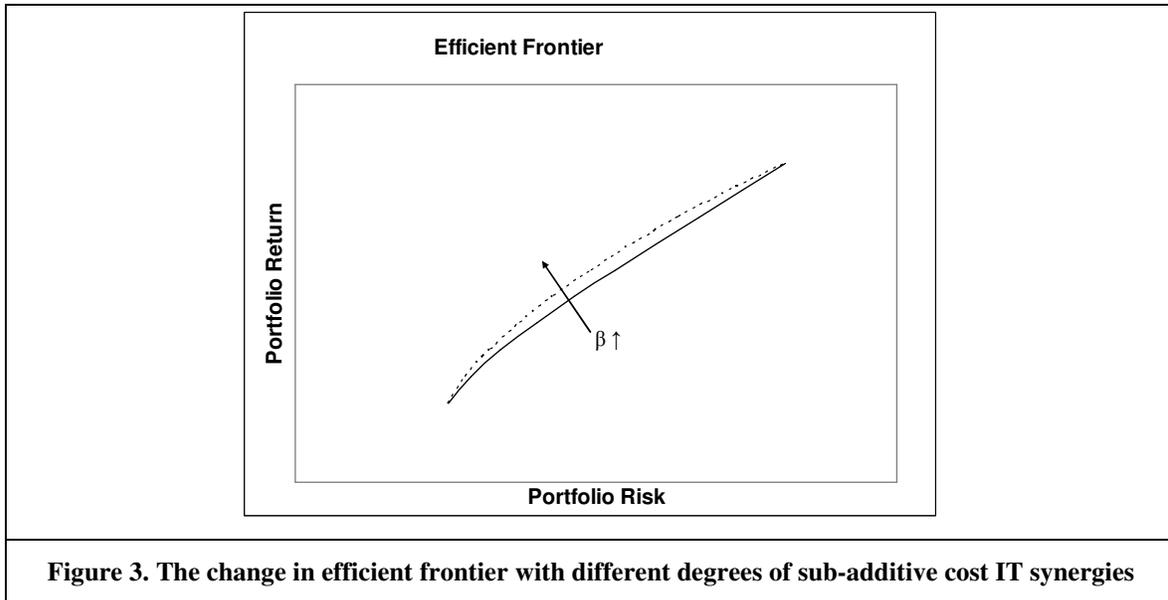
Table 2. IT Investment data for computational experiments				
ROI of IT investment Units	I (25%)	II (25%)	III (25%)	IV (25%)
Unit 1	1	1.9	2.1	3
Unit 2	2.5	2	5	4.5

**The Effect Of The Sub-Additive Cost IT Synergy**

Sharing IT resources and saving costs are often eligible when two IT units are implemented or operated simultaneously. Depending on technologies and resources of two IT units, some pairs can be characterized higher  $\beta$ , which means higher degree of sharing IT resources, and other pairs would be lower  $\beta$ . Figure 3 illustrates the change of efficient frontier as the *c-type* synergy of the two IT investment increases.

*Proposition 1. c-type synergy enables firms to obtain a superior IT portfolio.*

If the coordination cost for enhancement of *c-type* synergy is negligible, *c-type* synergy is always beneficial because it does not increase portfolio risk but increases portfolio return. According to the result in Figure 3, in the two unit portfolio, the firm of moderate risk tolerance benefit from greater *c-type* synergy. Because one unit is a high-risk IT investment and the other unit is a low-risk IT investment, the firms of moderate risk tolerance would diversify its investment. Thus, firms of moderate risk tolerance are more likely to have stronger incentive to enhance *c-type* synergy than firms of higher or lower risk tolerance. A managerial implication of this finding is that *c-type* synergy is always beneficial but firms of moderate risk tolerance are likely to obtain greater *c-type* synergy. Proof of the proposition 1 is attached in Appendix A.



**Figure 3. The change in efficient frontier with different degrees of sub-additive cost IT synergies**

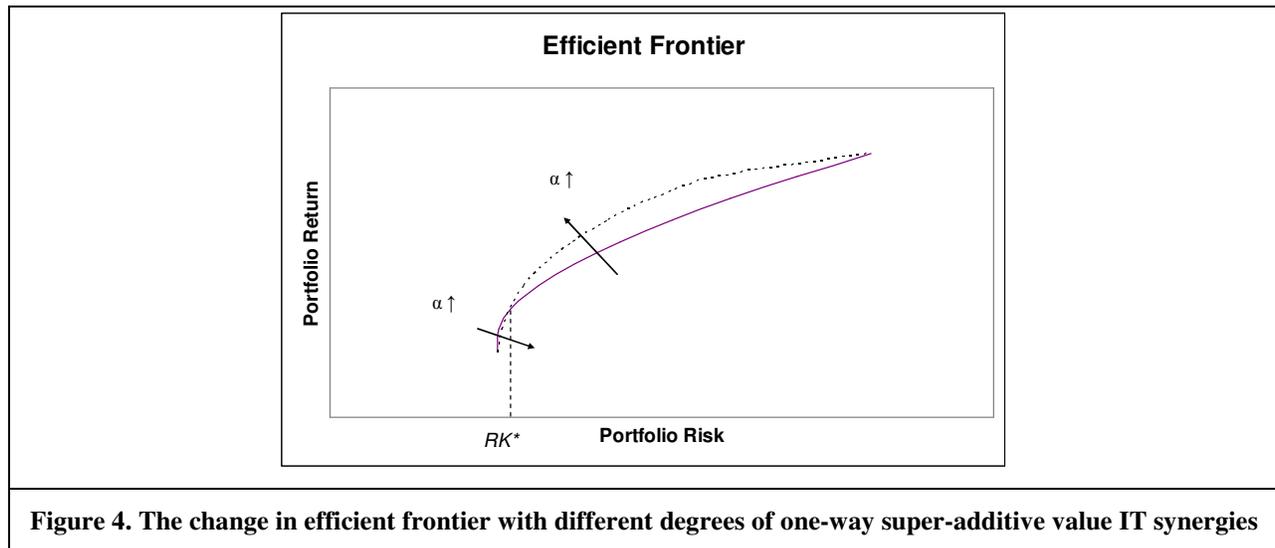
**The Effect Of One-Way Super-Additive Value IT Synergy**

We compared the efficient frontiers that a firm have with different level of *ov-type* synergy between the two IT investment units in Figure 4. The figure illustrates the shift of the efficient frontier as the level of *ov-type* synergy increases in case that the low-return and low-risk IT investment unit has one-way beneficial relationship on the high-return and high-risk IT investment unit. The dashed line represents the efficient frontier with higher level of *ov-type* synergy. There is a point that two efficient frontiers cross. According to the result, firms whose risk tolerance is higher than the point obtain a superior portfolio and firms whose risk tolerance is lower than the point have an inferior portfolio. We also found that the point move toward a point of higher risk as the correlation between the two unit decreases. It implies that the impact of *ov-type* synergy on portfolio risk becomes greater as covariance between the two units increases.

*Proposition 2a. Firms of high risk tolerance are likely to obtain a superior IT portfolio as the one-way super-additive value IT synergy becomes greater.*

*Proposition 2b. Firms of low risk tolerance may not be able to obtain a superior IT portfolio when the one-way super-additive value IT synergy becomes greater.*

Interestingly, the result implies that synergy is not always beneficial to a firm, which is different from conventional thinking about synergy. Firms whose risk tolerance is lower than a certain level appear to have an inferior IT portfolio. That may happen when the IT synergy increases portfolio risk more significantly than portfolio return. To the contrary, firms that relatively prefer taking high risk or have high risk tolerance are likely to benefit from the *ov*-type IT synergy. They appear to have a superior IT portfolio as higher *ov*-type synergy is enhanced between the two IT units. The mathematical analysis for proposition 2a and 2b are attached in Appendix B.



**Figure 4. The change in efficient frontier with different degrees of one-way super-additive value IT synergies**

### *The Effect of The Two-Way Super-Additive Value IT Synergy*

Figure 5 illustrates the effect of *tv*-type synergy on the IT portfolio selection of the firm. The effect of *tv*-type synergy appears to be similar to that of *ov*-type synergy in that the two efficient frontier cross at a point of a low portfolio risk. Firms of which risk tolerance is higher than the point have a superior set of portfolio and firms of which risk tolerance is lower than the cross point have an inferior set of portfolio.

*Proposition 3a. Firms of high risk tolerance are likely to obtain a superior portfolio as the two-way super-additive value IT synergy becomes greater.*

*Proposition 3b. Firms of low risk tolerance may not be able to obtain a superior portfolio when the two-way super-additive value IT synergy becomes greater.*

We found that *tv*-type synergy has greater impact to the firms that prefer taking higher risk than to the firms of low and high risk tolerance. Compared to Figure 7, the dashed line in Figure 8 is more skewed toward more to the right and upward. It implies that *tv*-type is more beneficial to the firms of high risk tolerance. In contrary, *ov*-type synergy appears to be more beneficial to the firms of moderate risk tolerance than to firms of high risk tolerance. But, firms of low risk tolerance may obtain an inferior portfolio when there is significant *tv*-type synergy between the two IT investment units.

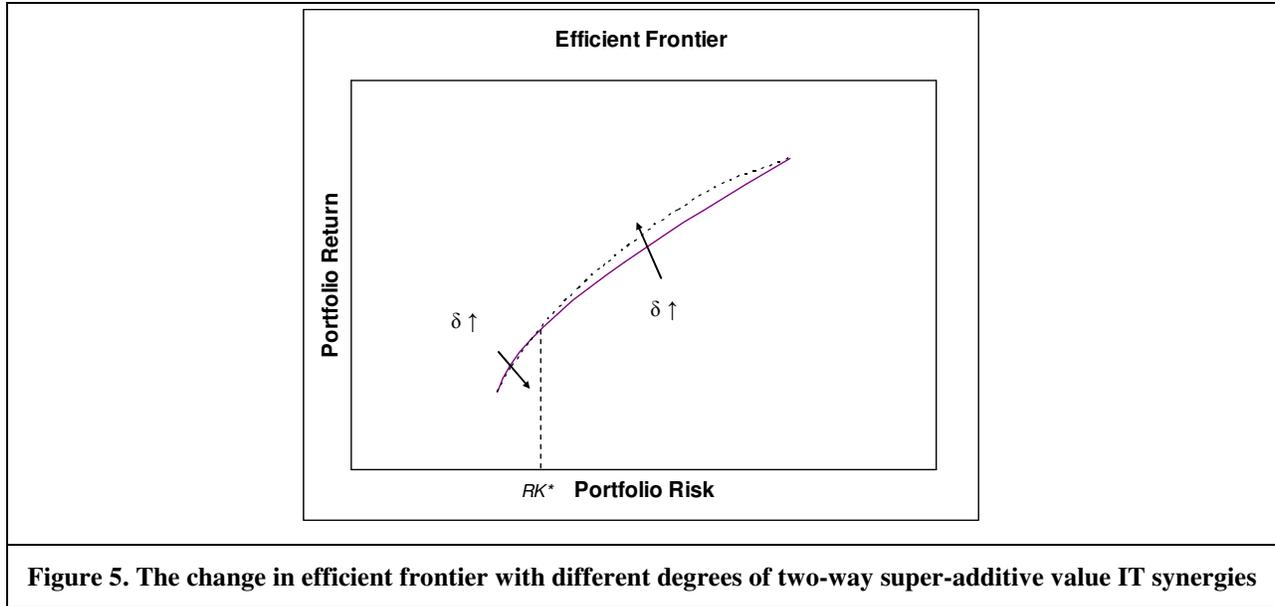


Figure 5. The change in efficient frontier with different degrees of two-way super-additive value IT synergies

## Implications

This study makes contributions to IS fields in several points. First, this study provides a methodological framework that helps firms to find a solution for their IT portfolio selection problems. Firms can use the efficient frontier as a tool in selecting an optimal IT portfolio. This tool can also be used for finding a firm's range of options and possible outcomes for alternative IT portfolios, and for recognizing marginal return they can earn by taking a unit of portfolio risk. This study presents IT investment problems from the CIO perspective by extending financial portfolio selection models. The model can provide a realistic solution when we consider the fact that the main concern of most firms is their financial performance. Our model captures not only the essence of the general investor's problem, namely, that of balancing between return and risk, but also characteristics of IT problems so that it can be distinguished from portfolio selection models in other areas.

Second, the impact of IT synergy on portfolio risk has been studied. Prior models have related IT synergy only with portfolio return, but our study provides more comprehensive picture of portfolio selection by modeling IT synergy as factor of portfolio risk as well as portfolio return. Although IT resources have been considered a major source of synergies due to its unique characteristics, few studies have articulated the effect of IT synergy on portfolio risk.

Third, this paper develops analytic models of IT synergy. Though there have been prior literature that tested effects of synergy empirically, there have been few studies that use analytic models to test effects of synergy. Portfolio return in our model is a non-linear function, which also distinguish our model from financial portfolio selection models.

Last, this paper addresses three types of IT synergies and discusses their different effects on a firm's IT portfolio selection. Our analysis can help firms make decisions in ways of integrating their information systems. Firms may focus on a certain type of IT synergy to achieve their goals of maximizing return and minimizing risk. In the real world, IT synergy is not free to gain. Additional cost of integration will occur to enhance *tv*-type synergy. Additional cost of coordination will occur to increase *c*-type synergy. Thus, it is important to estimate benefit of each type of IT synergy. According to our computational study, it is likely that firms of low risk tolerance may not benefit from IT synergy; thus we can suggest that they do not spend lots of money to enhance *ov*- and *tv*-type synergy. Firms of moderate risk tolerance can be suggested focusing on *c*-type synergy and *ov*-type synergy whereas firms of which risk tolerance is high can be suggested enhancing *tv*-type synergy.

Limitations of our paper include our assumption that a CIO of the firm selects an IT portfolio at a given time but this assumption may not be applicable to some companies, particularly for small-sized companies. They might usually evaluate individual decision making units of IT investment, such as IT projects. Another limitation is we assume the return is normally distributed. Depending on experts' practice, the return may not be normally distributed. In addition, our computational study could not cover all possible outcomes of IT synergy enhancement. For further

studies of this topic, analytical solutions can be useful to identify the conditions where IT synergy enhancement helps firms find a better IT portfolio.

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## References

- Agarwal, R. and Ferratt, T.W. "Enduring Practices for Managing IT Professionals," *Communication of the ACM* (45:9), 2002, pp. 73-79.
- Amihud, Y. and Lev, B. "Risk reduction as managerial motive for conglomerate mergers," *Bell Journal of Economics* (12), 1981, pp. 605-617.
- Asundi, J. and Kazman, R. "A Foundation for the Economic Analysis of Software Architectures," *Proceedings of the 3rd Workshop on Economics-Driven Software Engineering Research (EDSER-3)*, 2001.
- Bacon, C.J. "The Use of Decision Criteria in Selecting Information Systems/Technology Investment," *MIS Quarterly* (16:3), 1992, pp. 335-353.
- Ballester, E. and Romero, C. "Portfolio Selection: A Compromise Programming Solution," *The Journal of the Operational Research Society* (47:11), 1996, pp. 1377-1386.
- Barney, J. "Firm Resources and Sustained Competitive Advantage," *Journal of Management* (17:1), 1991, pp. 99-122.
- Benaroch, M. "Managing information technology investment risk: A real options perspective," *Journal of management information systems*, (19:2), 2002, pp. 43-84.
- Benaroch, M., Y. Lichtenstein, and Robinson, K. "Real options in information technology risk management: an empirical validation of risk-option relationships," *MIS Quarterly*, 2006, (30:4), pp. 827 - 864.
- Berinato, S. "Do the Math." CIO, Oct. 1, 2001 ([www.cio.com/archive/100101/math.html](http://www.cio.com/archive/100101/math.html)),
- Bradley, M., Desai, A. and Kim, E.H. "The rationale behind interfirm tender offers: information or synergy," *Journal of Financial Economics* (11), 1983, pp. 182-206.
- Byrd, T.A., Lewis, B.R., and Bryan, R.W. "The Leveraging Influence of Strategic Alignment on IT Investment: An Empirical Examination," *Information & Management*, (43:3), 2006, pp. 308-321.
- Cragg, P., King, M., and Hussin, H. "IT Alignment and Firm Performance in Small Manufacturing Firms," *Journal of Strategic Information Systems* (11:2), 2002, pp. 109-132.
- Christensen, H.A. and Montgomery, C.A. "Corporate economic performance: Diversification strategy versus market structure," *Strategic Management Journal* (2:4), 1981, pp. 327-343.
- Davis, R. and Thomas, L.G. (1993) "Direct estimation of synergy : a new approach to the diversity performance debate," *Management Science* (39:11), 1993, pp. 1134-1346.
- Dickinson, M.W., Thornton, A.C., and Graves, S. "Technology Portfolio Management: Optimizing Interdependent Projects Over Multiple Time Periods," *IEEE Transactions on Engineering Management* (48:4), 2001, pp. 518-527.
- Eckbo, B. E. 'Horizontal mergers, collusion, and stockholder wealth', *Journal of Financial Economics* (11), 1983, pp. 241-274.
- Farjoun, M. "The independent and joint effects of the skill and physical bases of relatedness," *Strategic Management Journal* (19:7), 1998, pp. 611-630.
- Feeny, D. F. and Willcocks, L. P. "Core IS Capabilities for Exploiting Information Technology," *Sloan Management Review* (39:3), 1998, pp. 9-21
- Fox, G.E., and Baker, N.R. "Project Selection Decision Making Linked to a Dynamic Environment," *Management Science* (31:10), 1985, pp. 1272-1285.
- Freund, R.J. "The Introduction of Risk into a Programming Model," *Econometrica* (24:3), 1956, pp. 253-263.
- Goold, M., and Campbell, A. "Desperately Seeking Synergy," *Harvard Business Review* (76:5), 1998, pp. 130-143.
- Hill, C.W.L. and Hoskisson, R.E. "Strategy and structure in the multiproduct firm", *Academy of Management Review*, (12:2), 1987, pp. 331-341.
- Jeffery, M., and Leliveld, I. "Best Practices in IT Portfolio Management," *MIT Sloan Management Review* (45:3), 2004.

- Jiang, J.J., and Klein, G. "Project Selection Criteria by Strategic Orientation," *Information & Management* (36), 1999, pp. 63–75.
- Keil, M. "Pulling the Plug: Software Project Management and the Problem of Project Escalation," *MIS Quarterly*, (19:4), 1995, pp. 421-447.
- Kersten, B., and Verhoef, C. "IT Portfolio Management: A Banker's Perspective on IT," *Cutter IT Journal*, (16:4), 2003, pp.34-40.
- Kroll, Laevy, and Markowitz, H.M. "Mean-Variance Versus Direct Utility Maximization," *Journal of Finance*, (34:1), 1984, pp. 47-61.
- Loch, C.H., and Kavadias, S. "Dynamic Portfolio Selection of NPD Programs Using Marginal Returns," *Management Science* (48:10), 2002, pp. 1227–1241.
- Lucas, H.C., and Moore, J.R., Jr. "A Multiple-Criterion Scoring Approach to Information System Project Selection," *Infor* (14:1), 1976, pp. 1–12.
- Lucas, Jr., H. *Information Technology: Strategic Decision Making for Managers*, Wiley, Hoboken, 2005
- Luftman, J., and Brier, T. "Achieving and Sustaining Business–IT Alignment," *California Management Review* (42:1), 1999, pp. 109-122
- Markowitz, H.M. *Portfolio Selection: Efficient Diversification of Investments*, 2nd Ed., Wiley, 1991.
- Markowitz, H.M. "Portfolio Selection," *Journal of Finance* (7:1), 1952, pp. 77-91.
- Maizlish, B., and Handler, R. *IT Portfolio Management: Unlocking the Business Value of Technology*, Wiley, 2005
- McFarlan, F.W. "Portfolio Approach to Information Systems," *Harvard Business Review*, 1974, p. 76.
- Miller, D.J. "Firms' technological resources and the performance effects of diversification: a longitudinal study," *Strategic Management Journal*, (25:11), 2004, pp. 1097-1119.
- Milgrom P. and Roberts, J. "Complementarities and fit Strategy, structure, and organizational change in manufacturing," *Journal of Accounting and Economics* (19), 1995, pp. 179 -208.
- Mittendorf, B. "Information revelation, incentives, and the value of a real option," *Management Science*, (50) 2004, pp. 1638–1645.
- Myers, S.C. "Finance theory and financial strategy," *Interfaces* (4), Jan-Feb 1984, pp. 26-37.
- Norton, D.P. *Creating Strategic Alignment and Readiness for IT*, Harvard Business School Publishing, 2002.
- Palepu, K. "Diversification strategy, profit performance and the entropy measure," *Strategic Management Journal* (6), July-Sep 1985, pp. 239-55.
- Palmer, J.W., and Markus, M.L. "The Performance Impacts of Quick Response and Strategic Alignment in Specialty Retailing," *Information Systems Research* (11:3), 2000, pp. 241–259.
- Panzar, J. C., and Willig, R. D. "Economies of scope," *American Economic Review*, (71:2), 1981, pp. 268-272.
- Penrose, T. *The Theory of the Growth of the Firm*, Oxford University Press, 1959
- Pralhad, C.K., and Krishnan, M.S. "The Dynamic Synchronization of Strategy and Information Technology," *Sloan Management Review* (43:4), 2002, pp. 24-33.
- Robins, J.A. and Wiersema, M. "A resource-based approach to the multibusiness firm," *Strategic Management Journal* (16), 1995, pp. 277-299.
- Rumelt, R.P. "Diversification strategy and profitability," *Strategic Management Journal* (3:4), 1982, pp. 359-369.
- Santhanam, R. and Kyparisis, G.J. "A Decision Model for Interdependent Information System Project Selection," *European Journal of Operational Research* (89:2), 1996, 1996, pp. 380–399.
- Santhanam, R., and Kyparisis, J. "A Multiple Criteria Decision-Model for Information-System Project Selection," *Computers & Operations Research* (22:8), Oct 1995, pp. 807–818.
- Schmidt, R.L. and Freeland, J.R. "Recent Progress in Modeling R&D Project-Selection Processes," *IEEE Transactions on Engineering Management* (39:2), 1992, pp.189-201
- Tanriverdi, H. "Information Technology Relatedness Knowledge Management Capability, and Performance of Multibusiness Firms," *MIS Quarterly* (29:2), 2005, pp. 311-334.
- Tanriverdi, H. "Performance Effects of Information Technology Synergies in Multibusiness Firms," *MIS Quarterly* (30:1), March 2006, pp. 57-77.
- Tanriverdi, H. and Venkatraman, N. "Knowledge relatedness and the performance of multibusiness firms," *Strategic Management Journal* (26:2), 2005, pp. 97-119
- Teece, D.J. "Economies of scope & the scope of the enterprise", *Journal of Economic Behavior and Organization* (1:3), 1980, pp. 223-247.
- Teece, D. J. "Towards an economic theory of the multiproduct firm," *Journal of Economic Behavior and Organization* (3), 1982, pp. 39-63.
- Verhoef, C. "Quantitative IT Portfolio Management," *Science of Computer Programming*, (45:1), 2002, pp. 1-96.

- Weill, P. and Vitale, M. "What IT infrastructure capabilities are needed to implement e-business models?" *Mis Quarterly*, (1:1), 2002, pp.17-34
- Wernerfelt, B. "A resource-based view of the firm," *Strategic Management Journal* (5), 1984, pp.171-180.
- Willig, R. "Technology and market structure," *American Economic Review* (69), 1978, pp. 346-351.
- Zhu, K. "The Complementarity of Information Technology Infrastructure and E-Commerce Capability: A Resource-Based Assessment of Their Business Value," *Journal of Management Information Systems* (21:1), Summer 2004, pp. 167-202.

## Appendix A

We can set  $x_1 = 1 - x_2$  for the portfolios lied on the efficient frontier. Portfolios in which  $x_1 + x_2 < 1$  will not lie on the efficient frontier because the expected return rate of both the two IT investment units are greater than one and the synergy coefficient  $\beta$  is positive. Let  $\beta_{12} = \beta$ ,  $\alpha_{12} = \alpha$ ,  $\delta_{12} = \delta$ ,  $\rho_{12} = \rho$  and  $x_2 = x$  (, which means  $x_1 = 1 - x$ ).

### Proof for Proposition 1.

We can rewrite portfolio return and risk of the two IT unit portfolio as follows.

$$RT = r_1 x_1 + r_2 x_2 + \beta En(x_1, x_2) \quad (1)$$

$$\begin{aligned} RK &= [Var(r_1 x_1 + r_2 x_2 + \beta_{12} En(x_1, x_2))]^{1/2} = [Var(r_1 x_1 + r_2 x_2)]^{1/2} \\ &= [(1-x)^2 \sigma_1^2 + x^2 \sigma_2^2 + 2(1-x)x\sigma_1\sigma_2\rho]^{1/2} \end{aligned} \quad (2)$$

Then, for  $\beta_2 > \beta_1$

$$\begin{aligned} RK(x_1, x_2, \beta_2) &= RK(x_1, x_2, \beta_1) \\ RT(\beta_2) - RT(\beta_1) &= (\beta_2 - \beta_1)En(x_1, x_2) > 0 \end{aligned}$$

Therefore, Proposition 1 is consistently supported.

### Mathematical Analyses for Proposition 2s.

We can rewrite portfolio return and risk of the two IT unit portfolio as follows.

$$RT = r_1(1-x) + r_2x + \alpha r_1(1-x)x \quad (3)$$

$$\begin{aligned} RK^2 &= Var(r_1x_1 + r_2x_2 + \alpha_{12}(r_1x_1)x_2) \\ &= x_1^2(1 + \alpha_{12}x_2)^2 \sigma_1^2 + x_2^2 \sigma_2^2 + 2x_1x_2\sigma_1\sigma_2\rho \\ &= (1-x)^2(1 + \alpha x)^2 \sigma_1^2 + x^2 \sigma_2^2 + 2r_1(1-x)(1 + \alpha x)x\sigma_1\sigma_2\rho \end{aligned} \quad (4)$$

First, we investigate the efficient frontier for firms of low risk tolerance. Then,  $x$  will be closer to zero than one because  $x$  represents the proportion of investment in the high-risk IT unit and the range of  $x$  is from zero to one. Assuming that  $x$  is close enough to zero, we can use the approximated equation as follows because the terms that are multiplied by more than square of  $x$  will be very small compared to constant terms and terms multiplied by  $x$ .

#### 1) For Proposition 2a: when $x$ is close to zero

$x = 0 + \varepsilon_1$ , ( $\varepsilon_1 > 0$  is small enough)

$$RK^2 \approx \sigma_1^2 + 2\{\sigma_1\sigma_2\rho + \sigma_1^2(\alpha - 1)\}\varepsilon_1 \quad (5)$$

$$\varepsilon_1 \approx \frac{RK^2 - \sigma_1^2}{2\sigma_1\{\sigma_2\rho - \sigma_1(1 - \alpha)\}} \quad (6)$$

By inserting (6) into (3),

$$\begin{aligned}
 RT(RK^2) &= r_1(1-x) + r_2x + \alpha r_1(1-x)x = -\alpha r_1x^2 + (\alpha r_1 - r_1 + r_2)x + r_1 \\
 &= -\alpha r_1 \left[ \frac{RK^2 - \sigma_1^2}{2\sigma_1 \{\sigma_2\rho - \sigma_1(1-\alpha)\}} \right]^2 + (\alpha r_1 - r_1 + r_2) \frac{RK^2 - \sigma_1^2}{2\sigma_1 \{\sigma_2\rho - \sigma_1(1-\alpha)\}} + r_1
 \end{aligned} \tag{7}$$

At the condition where  $RT(RK^2, \alpha_1) > RT(RK^2, \alpha_2)$  for  $\alpha_1 < \alpha_2$ , Proposition 2a will be supported.

**2) For Proposition 2b: when  $x$  is close to one**

$$x = 1 - \varepsilon_2, (\varepsilon_2 > 0 \text{ is small enough})$$

$$RK \approx \sigma_2^2 + 2\{(1 + \alpha)\sigma_1\sigma_2\rho - \sigma_2^2\}\varepsilon_2 \tag{8}$$

$$\varepsilon_2 \approx \frac{RK - \sigma_2^2}{2\{(1 + \alpha)\sigma_1\sigma_2\rho - \sigma_2^2\}} \tag{9}$$

By inserting (9) into (3)

$$\begin{aligned}
 RT(RK) &= r_1(1-x) + r_2x + \alpha r_1(1-x)x = -\alpha r_1x^2 + (\alpha r_1 - r_1 + r_2)x + r_1 \\
 &= -\alpha r_1 \left[ \frac{RK - \sigma_2^2}{2\sigma_2\{(1 + \alpha)\sigma_1\rho - \sigma_2\}} \right]^2 + (\alpha r_1 + r_1 - r_2) \frac{RK - \sigma_2^2}{2\sigma_2\{(1 + \alpha)\sigma_1\rho - \sigma_2\}} + r_2
 \end{aligned}$$

At the condition where  $RT(RK^2, \alpha_1) < RT(RK^2, \alpha_2)$  for  $\alpha_1 < \alpha_2$ , Proposition 2b will be supported.

**Mathematical Analyses for Proposition 3s.**

We can rewrite portfolio return and risk of the two IT unit portfolio as follows.

$$RT = r_1x_1 + r_2x_2 + \delta(r_1x_1 + r_2x_2)En(r_1x_1, r_2x_2) \tag{10}$$

$$RK^2 = Var(r_1x_1 + r_2x_2 + \delta(r_1x_1 + r_2x_2)En(r_1x_1, r_2x_2)) \tag{11}$$

Here, let  $En(r_1x_1, r_2x_2) = 4p_1p_2$ , where  $p_i = r_ix_i / \sum_i r_ix_i$ . The Entropy function has the maximum value at

$p_1 = p_2 = 0.5$  and the minimum value when  $p_1p_2 = 0$ . The Entropy function would be the simplest function that has the properties of Entropy functions. We found, even with the simplest Entropy function, we need additional set of estimated data, such as the variance of  $r_1r_2$  to prove Proposition 3. Thus, we conclude that computational study with specific sets of data is an appropriate method to examine the effect of *tv*-type synergy on IT portfolio selection.