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Candidate diversity and granularity in IT portfolio construction

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Abstract
The construction of a superior IT portfolio remains an open research question in prior literature. For addressing this gap, we investigate two unique characteristics of IT investment projects that may make it more or less likely to construct a superior IT portfolio in this study. We are mainly grounded on the modern portfolio theory to develop propositions regarding the relationships among such characteristics and their impacts on IT portfolio construction performance. Our methodology combines optimization modeling, real-world data, numerical simulation (Monte Carlo), and computational experiment. One main finding shows that, for any set of candidate IT investment projects, their attribute diversity and investment granularity could jointly influence the resultant IT portfolio construction performance. Even when a very tight budget is provided, a set of candidate IT investment projects with higher diversity and granularity would still generate a superior IT portfolio. In other words, the diversity and granularity of IT portfolio construction candidates can positively affect portfolio performance, although budget limits can impose a negative impact on the performance.

Keywords IT portfolio · Diversity · Granularity · Budget · Simulation · Computational experiment

1 Introduction

An IT portfolio is essentially a select set of IT investments. As IT continues to change the world, from barcodes to RFID and the internet of things (IoT), firms inevitably must consider investing in many IT projects to implement various initiatives [1]. Thus, considerable IT investment projects are proposed to meet infrastructural, informational, transactional, or strategic goals by acquiring and developing software, hardware, devices, networks, data centers, enterprise platforms, systems, applications and services. In addition, the current trend indicates that firms need to govern IT investments at the portfolio level, as urged by government polices such as the Cohen Act [2] and the Sarbanes–Oxley Act [3], as well as prompted by industry practices such as control objectives for information and related technologies (COBIT) [3]. Thus, it is generally suggested that IT investments be managed as a portfolio of assets, similar to a financial portfolio [4–11], in order to maximize their overall business value. However, IT portfolio construction is different from financial portfolio construction. For example, many IT investment

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projects do not equate with financial assets, such as stocks, when they are selected for portfolio construction. As a result, IT portfolio construction is one important research theme in the field of IT portfolio management (ITPM). In prior literature, the studies by McFarlan [12], Jeffery and Leliveld [8], and Aral and Weill [13] propose a number of categorical frameworks to classify IT portfolios. The studies by Bardhan et al. [4], Chiang and Nunez [14], Cho and Shaw [6] and Cho et al. [7], and Zimmermann et al. [15] propose several computational approaches for portfolio prioritization. However, while these studies have made great strides, considerable research gaps remain in the literature. For example, the studies by Cho and Shaw [6] and Cho et al. [7] suggest that synergy is one unique IT investment characteristic and it can be one determinant of IT portfolio construction performance. Following such a stream of research, what are the other relevant characteristics? How can they be useful for constructing a superior IT portfolio?

In view of these research gaps, we aim to investigate the characteristics that pertain to a set of candidate IT investment projects that may make it more or less likely to construct a superior IT portfolio. Our observations in practice, including evidence from a collaborative research program with a large US enterprise, also motivate us to conduct this study. We observe that when different sets of candidate IT investments are under consideration for portfolio construction, their attribute differences, decision making units, and budget limits are closely associated with the variations in performance. In this study, we thus develop several propositions and a computational model for theorizing and examining such associations and variations. Specifically, we define the aggregate attribute difference in a set of candidate IT investment projects as the degree of diversity [16]. The attributes that we consider in this study include benefit attributes, risk attributes, and cost attributes. This is based on the theoretical notion of diversity as variety, which is different from the concept of diversity as separation in financial portfolio studies. We define the composition of divisible decision-making units in a set of candidate IT investment projects as the degree of granularity. This is based on the theoretical notion of enterprise software production structural granularity [17].

The main findings of this study show that when a set of candidate IT investment projects involve greater diversity and granularity, it is more likely to construct a superior IT portfolio because of the enhanced freedom for selection and allocation. They can also mitigate the constraining impact of budget limits on IT portfolio construction performance. We derive such findings by computational experiment, Monte Carlo simulation, and a set of real-world IT investment business cases in a financial service division of a large US enterprise (the simulation seeds). Overall, the experiment includes 80,000 candidate IT investment projects. Each iteration involves 100 candidate IT investment projects for portfolio construction.

The major contributions of this study are twofold. First, we highlight that the diversity and granularity of IT portfolio construction candidates can positively affect portfolio performance, although budget limits can impose a negative impact on the performance. Such findings are rare in prior literature and complementary to the extant IT portfolio studies that focus on similar topics, such as Cho and Shaw [6], Cho et al. [7], and Karhade et al. [1]. In addition, we translate into ITPM the notion of diversity as the freedom of selection and the notion of granularity as the freedom of allocation. In other words, this study broadens the research area of ITPM. Second, although use of both computational simulation and experiment to examine theoretical propositions is not a novel methodological approach, it is still rare in prior IT portfolio studies. This study enhances IT portfolio research methodology richness.

The organization of this paper is as follows. First, we review key theoretical notions and derive the associated propositions. Next, we develop an IT portfolio construction model and then conduct computational experiments, simulations, and analyze results. Finally, we summarize the findings, discuss their research implications, and conclude this study by identifying future research directions.

2 A superior IT portfolio

A superior asset portfolio generates the greatest investment benefits without exceeding a planned level of investment risk. This concept is based on return-risk criterion, and the performance of IT portfolio construction can also be evaluated through similar rationale [6, 7]. While return-risk criterion is not the only portfolio evaluation standard, it is the one that can generally be effectively applied across different research disciplines including management, finance, and information systems, as demonstrated in prior literature [18, 19]. Return-risk criterion originates from modern portfolio theory (MPT) [20] and comprises one fundamental principle. The portfolio construction alternative with higher return but lower risk is superior, while the portfolio construction alternative with lower return but higher risk is inferior. A superior IT portfolio can be constructed by selecting a subset from a set of candidate IT investment projects where aggregate benefit is maximized, according to the risk tolerance level (risk appetite) that a firm plans to take and align with the firm's IT strategy [1].

2.1 Attribute diversity in candidate IT investment projects

In prior literature, the notion of diversity has several meanings and they vary with different research disciplines. In financial studies, diversity mostly is equivalent to the concept of separation, i.e., "do not put all your eggs in one basket" [21]. Such a concept aims to remove the interdependency between assets in a portfolio. On the other hand, the interdependent benefit, such as synergy, is a typical consideration in IT portfolio construction [4, 5].

In this study, we thus draw on the concept of diversity as variety in organizational management [22] and software engineering [16], rather than the notion of diversity as separation in financial studies. Specifically, *our diversity* (*variety*) *focus refers to the degree of attribute difference in a set of candidate IT investment projects*. When comparing any two sets of candidate IT investment projects, it is very common that each set shows a very different distribution of attributes. One obvious distinction between these distributions is their attributes' value variations. One set may present narrower variation scopes and thus their attribute difference is smaller, while the other set may present wider variation scopes such that their attribute difference is larger. For instance, the attribute of risk in one set of IS initiatives could concentrate on only a medium degree of scope, while the same attribute in the other set could be spread across low, medium, and high degrees of scope [1]. Similarly, the monetary benefit attribute in one set of candidate IT investment projects could vary within only one or few scopes, such as 500–1000 K, while the other set could vary within more scopes, such as 0–500 K, 500–1000 K, and > 1000 K. In other words, the levels of attribute differences vary across different sets of investments.

Furthermore, we posit that higher attribute diversity is a positive factor in constructing a superior IT portfolio. From a decision-making perspective, portfolio diversity as variety is the opposite of similarity. According to the economic utility theory, similarity generally means a sort of substitute degree between two things, two items, and so forth. Thus, one very important intrinsic value of diversity is based on the freedom of selection (i.e., the freedom of choice) [23, 24]. On the contrary, as the similarity of decision alternative increases, the freedom of selection decreases. This denotes that as the freedom increases, the dissimilarity of decision alternative increases. As previously stated, IT portfolio construction is a decision-making process for selecting and aggregating the best-fit attribute of candidate IT investment projects. Thus, a set of candidate IT investment projects with higher attribute diversity can be more flexible for portfolio construction, because a higher degree of attribute difference can provide higher freedom of selection. As a result, the likelihood of generating a superior IT portfolio is more likely to increase. Therefore, we derive the following proposition.

Proposition 1 *All else being equal, a set of candidate IT investment projects that involve higher diversity is more likely to generate a superior IT portfolio.*

2.2 Investment granularity in candidate IT investment projects

Like attribute diversity, the granularity of investment decision-making units varies in different IT portfolio construction contexts. For example, some IT portfolios are constructed with the divisible (proportional) investment decision-making unit [7], while others are constructed with the binary (all-or-nothing) investment decision-making unit [6]. In financial studies, the investment decision-making unit generally does not vary across different portfolio construction contexts. However, it is often seen that different IT investment projects do not have similar investment decision-making units because of their different structural granularity. In the IS literature, one very interesting implication in the study by Subramanyam et al. [17] is that different enterprise software products present different degrees of structural granularity. Some of them involve modular or loose-coupling components, and thus their development scopes are easily adjustable to meet different needs. Moreover, the literature regarding IT project investment selection suggests that many IT investment decision-making units are not binary, but divisible and proportional instead. For example, Fichman [25] highlights:

> …technology is divisible to the extent that it can be divided up for sequential implementation in such a way that each incremental segment positions the firm for a positive payoff even if no further implementation segments are pursued…

Thus, the notions of granularity [17] and divisible IT investment projects [25] together reflect that some IT investment projects with higher structural granularity can provide a proportional investment decision-making unit, while others can provide an all-or-nothing investment decision-making unit. It is also common in practice. For example, if an RFID IT investment project has a higher degree of structural granularity, it can offer a divisible investment decision-making unit, depending on whether there are more or fewer RFID readers, tags, and systems involved. By contrast, an IT investment project for constructing a one-size data warehouse center can offer only an indivisible investment decision-making unit because of a lower degree of structural granularity. Hence, *investment granularity in this study refers to the degree of divisible investment decision-making units within a set of candidate IT investment projects.*

Accordingly, we posit that higher granularity is a favorable factor in constructing a superior IT portfolio. As previously stated, the return-risk criterion is based on MPT and it can determine asset portfolio construction performance. This suggests that one convincing way to enhance portfolio construction performance is to allocate more funds to the assets that involve more return, less risk, i.e., the more beneficial assets. From a decision-making perspective, a divisible investment unit is more flexible than an indivisible investment unit, because it can offer more freedom of allocation. Thus, constructing an IT portfolio based on a set of IT investment projects with higher granularity has the greater potential for allocating more funds to the more beneficial projects. Consequently, the likelihood of generating a superior IT portfolio would increase. Therefore, we derive the following proposition.

Proposition 2 *All else being equal, a set of candidate IT investment projects that involve higher investment granularity is more likely to generate a superior IT portfolio.*

Further, we expand on Propositions 1 and 2 to consider the possible joint impact of diversity and granularity on IT portfolio construction performance.

2.3 The joint impact of diversity and granularity

By synthesizing Propositions 1 and 2, we further posit that there is a joint impact of diversity and granularity. As stated above, it is understandable that both higher diversity and granularity are favorable for improving IT portfolio construction performance. However, the granularity-induced allocation advantage in IT portfolio construction is essentially a type of comparative advantage. According to MPT, only the more beneficial asset (e.g., more return and less risk) is worth the allocation of more funds. When assets are very similar to each other (i.e., very low diversity), there will be no so-called "more beneficial asset" that should be worth the allocation of more funds. Namely, the allocation of more or less funds to which asset hardly makes any difference to improve overall portfolio performance. For example, one extreme situation is when there is only one candidate asset to be considered for portfolio construction. In this situation, the portfolio construction performance barely can change, no matter whether the asset has a completely divisible investment decision making unit. The impact of IT project investment granularity on IT portfolio construction is likely to be very limited, when the investment diversity is very low. Therefore, we derive the following proposition.

Proposition 3 *All else being equal, a set of candidate IT investment projects that involve very low diversity is less likely to generate a superior IT portfolio, even though this candidate set involves very high granularity.*

2.4 Budget constraints in IT portfolio construction

Lastly, one important condition that underlies the development of all the aforementioned positions is that IT portfolio construction is subject to budget limits, an imposed constraint in almost any organizational context [15, 26–28]. Generally, a budget limit refers to a limited amount of capital or financial support for constructing an IT portfolio based on a set of candidate IT investment projects. In other words, although we have proposed a certain number of favorable factors in IT portfolio construction, a budget limit represents one unfavorable factor in constraining IT portfolio construction performance.

We posit that the degree of the decrease in IT portfolio construction performance due to budget limits may vary with different degrees of attribute diversity and investment granularity in different sets of candidate IT investment projects. In prior literature, MPT does not consider any budget limit in its original formula. In addition, while a number of extant IT portfolio studies include budget limits in their models (e.g., [5–7]), they do not consider the influence of the characteristics of candidate IT investment projects. Thus, there is often a naïve assertion that, given any two sets of candidate IT investment projects, the set with a tight budget limit (less budget) will generate the inferior IT portfolio than the other set with a loose budget limit (more budget). From a decision-making perspective, it is understandable that a tight budget limit (less budget) generally denotes that there is less freedom of selection or less freedom of allocation in IT portfolio construction. However, as stated earlier, greater diversity and granularity can enhance freedom of selection and freedom of allocation. This means that the impacts of such favorable characteristics can mitigate or even offset the unfavorable constraining impact of a budget limit in IT portfolio construction, depending on which side's impact is stronger. It is possible that, under some conditions, one set of candidate IT investment projects with a tight budget limit (less budget) may still generate a more superior IT portfolio than the other set of candidate IT investment projects with a loose budget limit (more budget). Therefore, we derive the following proposition.

Proposition 4 *All else being equal, it is possible that a set of candidate IT investment projects that involve both higher diversity and granularity, but share a tight budget limit (less budget), can generate a more superior IT portfolio than a set of candidate IT investment projects that involve both lower diversity and granularity, but share a loose budget limit (more budget).*

3 Methodology

In this study, we employ a methodology based on computational simulation and experiments to examine the propositions. Simulation is a method that increasingly shows its significance for theory development in management research [29, 30]. This method is very suitable for addressing the research that may be concerned with analytical intractability or observational biases in empirical data. Moreover, computational simulation and experiments complement each other. They are both based on computational representation to operationalize the underlying theoretical logic in research work and often executed iteratively under varying scenarios or pre-conditions to derive results. There is a stream of IS studies that utilized similar computational approaches based on simulation [31–35]. Specifically, the approach that we adopt in this study combines optimization modeling, real-world data, numerical simulation (Monte Carlo), and computational experiments.

This optimization model (1) aims to construct an IT portfolio based on a set of candidate IT investment projects. The model objective is to maximize IT investment project portfolio benefits while minimizing risk according to the planned risk-taking level (risk tolerance level) and within the budget constraint. It is an extension of the IT portfolio selection model developed by Cho [5], Cho and Shaw [6] and Cho et al. [7]. Also, Zimmermann et al. [15] and Fridgen et al. [27] have presented part of the analogous structures in their models including the weighted risk aversion parameters, which are essentially consistent with a financial MPT model [20]

$$\max\left\{\left(\sum_{i=1}^{n} x_i v_i + \sum_{i=1}^{n}\sum_{j>i}^{n} x_i x_j v_{ij}\right) - \lambda\left(\sum_{i=1}^{n} x_i r_i + \sum_{i=1}^{n}\sum_{j>i}^{n} x_i x_j r_{ij}\right)\right\}$$
$$\text{s.t.}\quad \left(\sum_{i=1}^{n} x_i c_i\right) < C_b \tag{1}$$

As presented in Table 1, for each candidate IT investment project (x_i) to be considered in the model (1), it needs to provide the following three main attributes: benefit (v_i), risk (r_i), and cost (c_i). Several pairs of these IT investment projects (x_i, x_j) may co-create interdependent benefits (v_{ij}) and risks (r_{ij}) [6]. In addition, C_b denotes a predetermined IT budget threshold. λ denotes a weight coefficient for balancing IT portfolio benefit and risk. Conceptually, this defines the amount of benefit that can be offset in terms of a unit of risk in IT portfolio construction. In financial studies, this weight coefficient is often called the risk aversion coefficient, indicating the level of risk that an investor would like to take. Mathematically, λ can be regarded as a Lagrange multiplier and derived from the Lagrange transformation [5–7] by adding a specific risk-taking constraint to the model.

We operationalize the key concepts in our propositions with computational metrics (numerical values). To compare the performance of any two IT portfolio constructions, we use the ratio of benefit and risk to determine which is superior to the other. We use statistical distribution variance to compare degrees of attribute diversity in different sets of candidate IT investment projects. In other words, we use it as a measure to determine how different the numbers in an attribute distribution are. For granularity, we use a count-based method for measurement, similar to the way granularity is assessed in the study by Subramanyam et al. [17]. We count the number of a set of n candidate IT investment projects where their investment decision variables are divisible (proportional) decision-making units. Lastly, for each candidate set of IT investment projects, we use an overall cost percentage threshold to measure its budget constraint.

We design eight experiment scenarios where different sets of candidate IT investment projects can systematically involve higher or lower degrees of diversity (Hd vs. Ld), a higher or lower degree of granularity (Hg vs. Lg), and a looser budget constraint (higher or more budget) or tighter budget constraint (lower or less budget) (Hb vs. Lb) (Table 2). The scenarios range from higher-diversity–higher-granularity–higher-budget (HdHgHb) to lower-diversity–lower-granularity–lower-budget (LdLgLb). The simulated inputs for these scenarios are generated by a Monte

Table 1 Model notation

Notation	Definition
n	The quantity of a set of candidate IT investment projects
x_i	The *i*th IT investment project decision variable
v_i	The investment benefit associated with the *i*th IT investment project
r_i	The investment risk associated with the *i*th IT investment project
c_i	The investment cost associated with the *i*th IT investment project
v_{ij}	The interdependent investment benefit associated with the *i*th and *j*th IT investment projects
r_{ij}	The interdependent investment risk associated with the *i*th and *j*th IT investment projects
C_b	Budget constraint
λ	Risk tolerance coefficient

Table 2 The experimental treatments and settings

Experimental treatments	Simulation settings
Higher diversity (Hd)	v_i ~ N (0.19, 0.25), r_i ~ N (0.5, 0.3), c_i ~ N (0.2, 0.02)
Lower diversity (Ld)	v_i ~ N (0.19, 0), r_i ~ N (0.5, 0), c_i ~ N (0.2, 0)
Higher granularity (Hg)	$0 \le x_i \le 1$
Lower granularity (Lg)	$x_i = 0$ or 1
Tighter budget constraint (less budget) (Hb)	$C_b \sim \mathrm{U}\left(0.5\sum_{i=1}^{n} c_i, 0.8\sum_{i=1}^{n} c_i\right)$
Looser budget constraint (more budget) (Lb)	$C_b \sim \mathrm{U}\left(0.2\sum_{i=1}^{n} c_i, 0.5\sum_{i=1}^{n} c_i\right)$

Carlo simulation to ensure that a variety of possible inputs can be considered. For each higher diversity-related attribute including benefit, risk, and cost, the attributes are simulated based on the normal distribution, i.e.,$v_i \sim N\left(\mu_v, \sigma_v^2\right)$, $c_i \sim N\left(\mu_c, \sigma_c^2\right), r_i \sim N\left(\mu_r, \sigma_r^2\right)$ [5–7]. To determine the values of μ_v, μ_c, μ_r, and σ_v, σ_c, σ_r, we refer to a set of real-world IT investment business cases in a financial service division within a large US enterprise. Benefit is estimated by NPV in this real-world data set. This approach is widely used in capital budgeting [36, 37]. Risk estimation is based on the scoring approach (e.g., 1–100 points). In prior literature, several studies have shown the similar approaches for project risk estimation [38–41]. Essentially, the risk scoring approach is based on the economic utility theory by multiplying risk impact and probability. Such risk impact factors can include technical complexity, managerial difficulty, and environmental unpredictability [39, 42]. In addition, since the data set is proprietary and non-disclosable, the number associated with the set is reformatted and presented on a scale between 0.0 and 1.0 in this study. For example, if mean (μ_v) and variance (σ_v^2) of a benefit are \$2000 K and \$2600 K, and the largest benefit is \$10,000 K and the lowest benefit is \$60 K in the data set, we use 0.2 to represent its mean and 0.26 to represent its variance, i.e., $\mu_v = (2000-60)/(10{,}000-60)$ and $\sigma_v^2 = (2600-60)/(10{,}000-60)$. Similarly, if mean ($\mu_r$) and variance ($\sigma_r^2$) of the risk score (point) are 50 and 30, and the largest one is 100 and the lowest one is 1, we present only 0.5 and 0.3, i.e., $\mu_v = (50-1)/(100-1)$ and $\sigma_v^2 = (30-1)/(100-1)$. In the same vein, each lower diversity-related attribute, including benefit, risk, and cost, is simulated based on a uniform distribution and the real-world data set such that variance degrees would be very low. In this way, for different sets of candidate IT investment projects with lower or higher attribute diversity in the experiment, their benefit, risk, and cost will be normally distributed to the same degree as mean but with different degrees of variance. Second, each higher granularity related variable (x_i) is simulated as a divisible decision-making unit. Each lower granularity related variable is simulated as a binary decision-making unit. Third, the loose budget constraint (less budget) and tight budget constraint (more budget) are simulated by two randomly predetermined ranges for setting budget thresholds. They are 20–50% and 50–80%. These main experimental treatments and simulation settings are summarized in Table 2.

The remaining settings in the experiment are controlled to be constant or vary randomly across all the scenarios. The quantity of each set of candidate IT investment projects is 100 (n), and there will be 10 different degrees of risk tolerance levels (λ) from low to high (less risk-taking to very high risk-taking) considered in every IT portfolio construction experiment. Moreover, the occurrences of interdependent benefit (v_{ij}) and risk (r_{ij}) are simulated with an asymmetric random binary array $\left(i * j = \frac{n*(n-1)}{2}\right)$. In this array, each row presents a probability space where interdependency would occur. The interdependency occurrence probability is configured as 10%, based on a count of identified interdependency in the collected real-world data set. Namely, once 1 instead of 0 appears in a cell of the array, it indicates that an interdependency between IT investment projects i and j must be considered. Then, the numbers (values) of their associated interdependent benefit (v_{ij}) and risk (r_{ij}) are simulated. The simulation follows the same method for simulating the general benefit and risk based on the normal distribution. All these computational experiment scenarios and simulations are executed by an optimization modeling and simulation package (LINGO).

4 Experiment results

The overall IT portfolio construction performance results based on a scale between 0.0 and 1.0 are the numbers presented in Table 3, which are in the form of the averaged benefit of optimal IT portfolios (optimal IT portfolio construction choices) under each experimental scenario (columns) and risk tolerance level (rows). Their standard deviations are presented in Table 4. These results are generated through more than 8000 successful computational iterations (i.e., 100 sets × 8 scenarios × 10 risk tolerance levels).

Table 3 The performance results

Risk tolerance levels	Experimental scenarios							
	HbHdHg	HbHdLg	HbLdHg	HbLdLg	LbHdHg	LbHdLg	LbLdHg	LbLdLg
0.1	0.3191	0.3172	0.0773	0.0772	0.2966	0.2925	0.0773	0.0772
0.2	0.4573	0.4562	0.1558	0.1557	0.3659	0.3599	0.1558	0.1557
0.3	0.5870	0.5858	0.2367	0.2367	0.4361	0.4309	0.2368	0.2364
0.4	0.6637	0.6628	0.3177	0.3176	0.5051	0.5019	0.3177	0.3159
0.5	0.7646	0.7631	0.4066	0.4061	0.5213	0.5183	0.3572	0.3588
0.6	0.8168	0.8157	0.4823	0.4815	0.6415	0.6389	0.4622	0.4608
0.7	0.8422	0.8412	0.5488	0.5478	0.6138	0.6106	0.4743	0.4694
0.8	0.9010	0.8996	0.6421	0.6406	0.7011	0.6974	0.5259	0.5279
0.9	0.9351	0.9344	0.7156	0.7119	0.7343	0.7315	0.5808	0.5810
1	0.9595	0.9587	0.8077	0.8062	0.7454	0.7440	0.5754	0.5755
Overall AVG	0.7246	0.7235	0.4391	0.4381	0.5561	0.5526	0.3763	0.3759

Table 4 The performance standard deviation results

Risk tolerance levels	Experimental scenarios							
	HbHdHg	HbHdLg	HbLdHg	HbLdLg	LbHdHg	LbHdLg	LbLdHg	LbLdLg
0.1	0.0673	0.0673	0.0240	0.0240	0.0440	0.0419	0.0240	0.0240
0.2	0.0546	0.0546	0.0228	0.0228	0.0191	0.0206	0.0228	0.0229
0.3	0.0418	0.0421	0.0211	0.0211	0.0730	0.0721	0.0210	0.0212
0.4	0.0320	0.0321	0.0248	0.0247	0.0260	0.0269	0.0248	0.0233
0.5	0.0366	0.0364	0.0301	0.0301	0.0201	0.0215	0.0178	0.0181
0.6	0.0303	0.0306	0.0245	0.0244	0.0249	0.0243	0.0150	0.0142
0.7	0.0386	0.0386	0.0278	0.0278	0.0145	0.0148	0.0127	0.0106
0.8	0.0163	0.0168	0.0210	0.0208	0.0663	0.0668	0.0544	0.0549
0.9	0.0249	0.0250	0.0362	0.0363	0.0227	0.0226	0.0103	0.0104
1	0.0184	0.0193	0.0257	0.0283	0.0373	0.0360	0.0125	0.0122
AVG	0.0154	0.0153	0.0049	0.0049	0.0216	0.0211	0.0130	0.0134

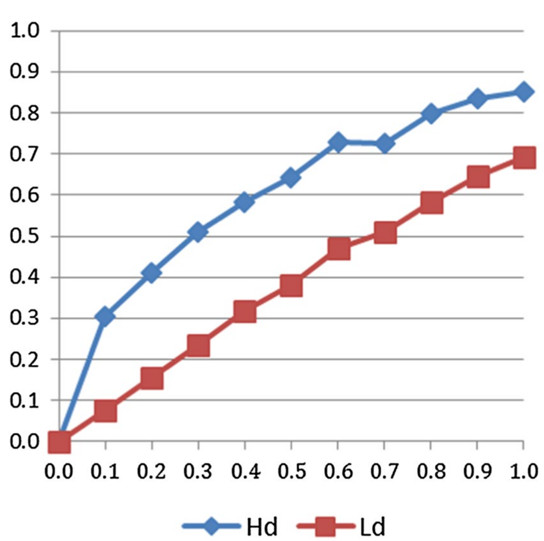

Fig. 1 Comparison of higher diversity results and lower diversity results

As presented in Fig. 1, the averaged results of higher diversity scenarios, including HbHdHg, HbHdLg, LbHdHg, and LbHdLg (i.e., Hd), show greater benefit at each risk tolerance level than those with lower diversity scenarios, including HbLdHg, HbLdLg, LbLdHg, and LbLdLg (i.e., Ld). This result signifies that, on average, the set of candidate IT investment projects with higher degrees of attribute diversity is more likely to generate superior IT portfolio construction choices which supports Proposition 1.

Moreover, the averaged results of higher granularity scenarios include HbHdHg, HbLdHg, LbHdHg, and LbLdHg (i.e., Hg) and those with lower granularity scenarios include HbHdLg, HbLdLg, LbLdLg and LbHdLg (i.e., Lg). As presented in Fig. 2, the blue line generally dominates the red line, although the difference between the two lines is not very large. This suggests that the set of candidate IT investment projects with higher degrees of investment granularity is more likely than the set of candidate IT investment project

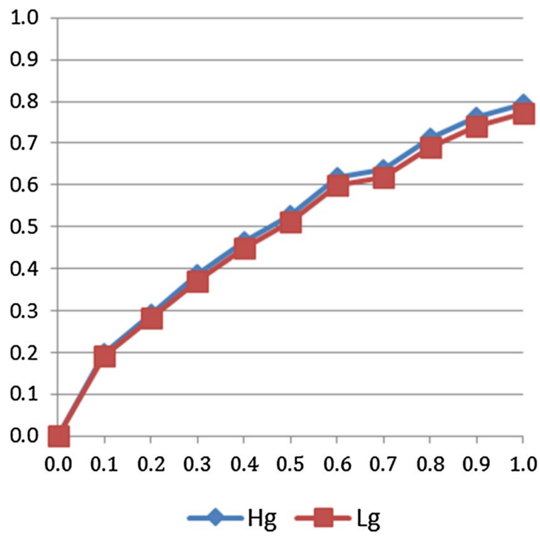

Fig. 2 Comparison of higher granularity results and lower granularity results

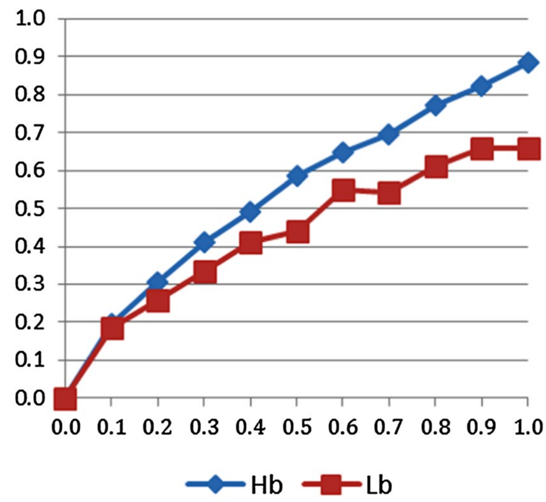

Fig. 4 Comparison of looser budget constraint (higher or more budget) results and tighter budget constraint (lower or less budget) results

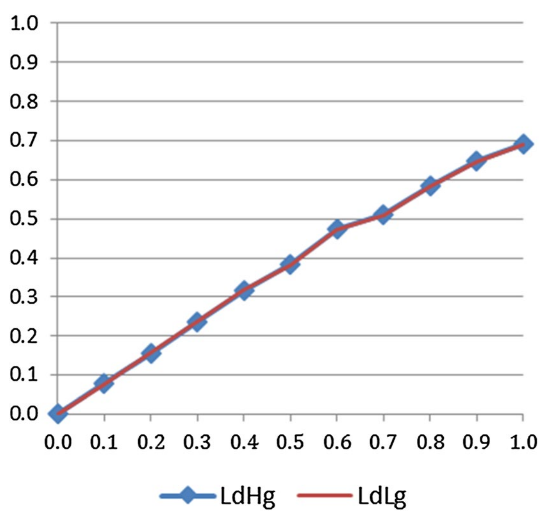

Fig. 3 Comparison of lower diversity with higher granularity results and lower diversity with lower granularity results

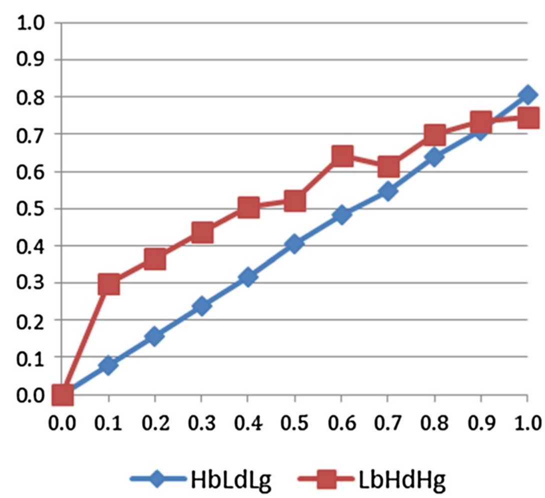

Fig. 5 Comparison of looser budget constraint (higher or more budget) with lower diversity and granularity results and tighter budget constraint (higher or less budget) with higher diversity and granularity results

with lower degree of investment granularity to generate superior IT portfolio construction choices, which supports Proposition 2.

As presented in Fig. 3, the averaged results of the lower diversity and higher granularity scenarios, including HbLdHg and LbLdHg (i.e., LdHg), and those with lower diversity and lower granularity, including HbLdLg and LbLdLg (i.e., LdLg), show the very similar level of benefit at each tolerance level (Fig. 3). This result denotes that, on average, the set of candidate IT investment projects with lower degrees of attribute diversity but higher degrees of investment granularity and the set of candidate IT investment projects with lower degrees of attribute diversity and lower degree of investment granularity are likely to generate almost indistinguishable IT portfolio construction choices, which supports Proposition 3.

As presented in Fig. 4, the averaged results of all of the scenarios with tighter budget constraints (less budget), including LbHdHg, LbHdLg, LbLdHg, and LbLdLg (i.e., Lb), show less benefit at each risk tolerance level compared with those with looser budget constraints (more budget), including HbHdHg, HbHdLg, HbLdHg, and HbLdLg (i.e., Hb).

However, as presented in Fig. 5, there is an overlap between the blue and red lines. This means that the blue line is not generally on the upper side of the red line. Rather, it sometimes can be on the lower side of the red line. The two lines respectively represent the portfolio construction performance under the condition of more budget with lower diversity and granularity, and the performance under the condition of lesser budget with greater diversity and granularity. In other words, it is not impossible that a set of candidate IT projects that involve both higher diversity and granularity, but share a tight budget, can generate a more superior IT portfolio than a set of candidate IT projects that involve both higher diversity and granularity, but share a loose budget. This signifies that, even given a tighter budget, it is not impossible to generate superior IT portfolio construction choices, which supports Proposition 4.

In addition, the statistical significance of those performance differences between each two experiment scenarios are computed by pair-wise *t* tests, with all possible comparison pairs presented in Table 5. Such results provide more details about the differences for IT portfolio construction performance in the experiments. For example, as seen in Fig. 3, IT portfolio construction performance of LdHg (lower diversity with higher granularity) and that of LdLg (lower diversity with lower granularity) is almost indistinguishable with each other. In detail, the pair-wise *t* tests show that the performance difference between HbLdHg and HbLdLg is 7.2207E−07, and the performance difference between LbLdHg and LbLdLg is 0.371879814. Both *p* values are among the largest values in the *t* test results, but one is statistically significant and the other is not.

In general, the results above support the aforementioned propositions and several of them are worthy of further discussion.

5 Summary of findings and discussion

Briefly stated, the main findings of this study are that the likelihood of constructing a superior IT portfolio can increase when the portfolio construction targets (e.g., a set of candidate IT project investments) involve higher diversity and granularity. This is because increased diversity and granularity enhance the freedom of selection and allocation in portfolio construction. They also mitigate the constraining impact of budget limits. As a result, it is more likely to select better targets and allocate more funds to them, so as to improve IT portfolio construction performance. Moreover, although some of our findings seem similar to some implications of MPT, they are essentially different from their contextual focuses. For instance, one primary rationale that underlies MPT is that higher diversity can help remove interdependencies among assets. However, our main findings regarding diversity are not based on removing interdependencies but improving the freedom of selection in portfolio construction. Relatedly, MPT does not consider the freedom of allocation. This is largely because MPT assumes that assets consistently involve maximum granularity (divisibility), but this assumption can rarely translate into many IT investment projects. Lastly, MPT does not consider the impact of budget limits, but we show that such an impact on IT portfolio construction is significant. Overall, while several important findings in this study might seem to repeat what MPT [20] has suggested, they and MPT essentially have different focuses (Table 6).

6 Concluding remarks

To conclude, what we highlight in this study is that IT portfolio construction has many more subtle considerations than financial portfolio construction, although both of them share the similar objectives of maximizing return, minimizing risk, and balancing them. For example, the study by Jeffery and Leliveld [8] defines ITPM as follows:

Table 5 The statistical significance results

	HbHdHg	HbHdLg	HbLdHg	HbLdLg	LbHdHg	LbHdLg	LbLdHg	LbLdLg
HbHdHg	–							
HbHdLg	1.45813E−25							
HbLdHg	7.13012E−64	9.78504E−64						
HbLdLg	2.52247E−64	3.45948E−64	7.2207E−07					
LbHdHg	1.09438E−39	2.09281E−39	3.0291E−21	1.18174E−21				
LbHdLg	1.07575E−40	2.04393E−40	1.1116E−20	8.88E−20	4.02141E−21			
LbLdHg	1.92589E−80	3.27791E−80	2.4727E−12	3.45521E−12	3.28367E−69	3.8148E−69		
LbLdLg	6.32189E−81	1.08057E−80	1.4097E−12	1.96536E−12	8.97883E−70	9.9472E−70	0.371879814	–

Table 6 Contrasting MPT focuses with This Study Focuses

MPT	This study
Diversity (diversification) as separation is focused on removing asset interdependency (correlation) in financial portfolio construction	Diversity as variety is focused on enhancing the freedom of selection in IT portfolio construction
Decision making unit in financial portfolio construction always has the highest granularity (the perfect divisibility)	Decision making unit in IT portfolio construction can have low or high granularity. When the degree of granularity as the freedom of allocation increases, the construction performance increases
The joint impact of diversity and granularity (divisibility) on financial portfolio construction performance is not concerned	There is a joint impact of diversity and divisibility on IT portfolio construction performance
The impact of budget limit on financial portfolio construction performance is not concerned	Budget limit, diversity, granularity and their interactions together influence IT portfolio construction performance

> …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…

As presented in this paper, this is just one basic definition for constructing an IT portfolio. Other than that, IT portfolio construction needs to consider that different sets of candidate IT investment projects have different degrees of diversity and granularity. These characteristics, along with different degrees of IT portfolio budget limits, can significantly affect IT portfolio construction performance. On the other hand, financial portfolio construction and the related financial theories, such as MPT, generally do not have such considerations. In a way, one main idea that we conceive when initializing this study is that ITPM is analogous to organizational management. For example, IT portfolio construction is essentially a management of multiple investments in IT related resources for achieving organizational goals. As a cornerstone in modern organizational management, Penrose's theory has long noted that resources selection and allocation are the bottlenecks to improving organizational performance [43, 44]. In other words, what we are after in this study is to use the general concepts in organizational management to extend financial MPT to including unique IT investment decision making contexts for improving IT portfolio construction performance.

Finally, what we establish in this study is one step in the direction of addressing key determinants or factors for improving IT portfolio construction performance. We recognize that this study has limitations and future research should focus on addressing them. One obvious assumption of this study is that any candidate IT investment project can be compared with another project rationally in portfolio construction. However, it is not uncommon that some managers or firms always treat some candidate IT investment projects as imperative and thus they have the top priority in IT portfolio construction. Also, we have not considered the flexibility in terms of managing time uncertainty [45] in IT portfolio. Besides, one implicit assumption that underlies this study is that IT investment project size proportionally determines its expected benefit/risk. While this linear relationship assumption is consistent with MPT, the non-linear relationship may exist in some situations. We thus additionally include the experiment results that consider such non-linear situations in the following "Appendix" section.

Appendix

A non-linear relationship between IT investment project granularity and benefit/risk is considered when generating these results (Figs. 6, 7, 8, 9, 10). These results are generated by 100 data sets × 8 scenarios × 10 risk tolerance levels. In general, such results and the results as presented above in the main text (Figs. 1, 2, 3, 4, 5) are comparable. Noticeably, the blue line in Fig. 5 (i.e., the linear situation) seems to present the greater IT portfolio benefit than that of Fig. 10 (i.e., the non-linear situation), if their respective dominances over the red lines are taken as their comparison basis. As stated, Figs. 5 and 10 are both focused on the

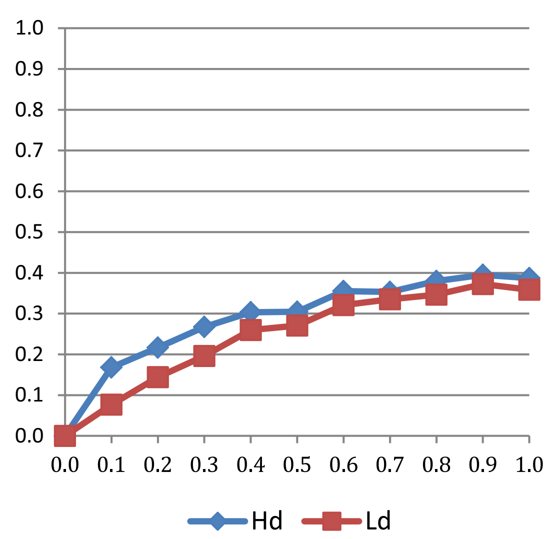

Fig. 6 Comparison of higher diversity results and lower diversity results

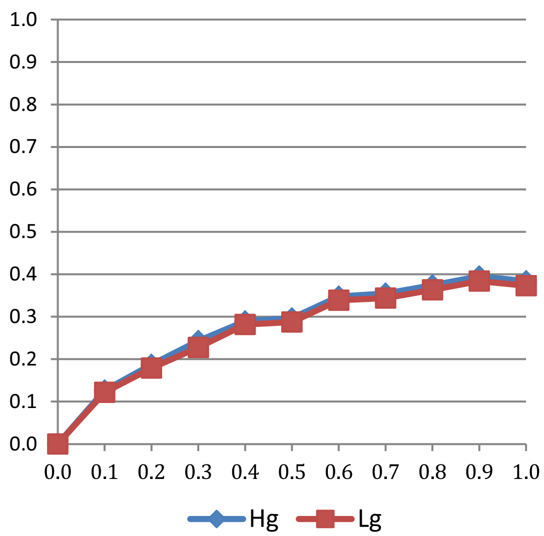

Fig. 7 Comparison of higher granularity results and lower granularity results

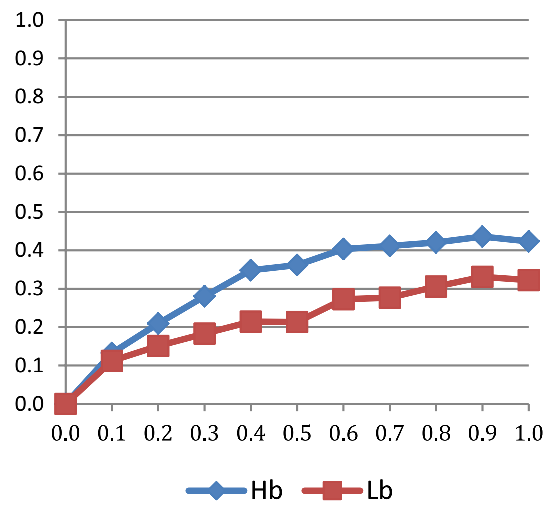

Fig. 9 Comparison of looser budget constraint (higher or more budget) results and tighter budget constraint (lower or less budget) results

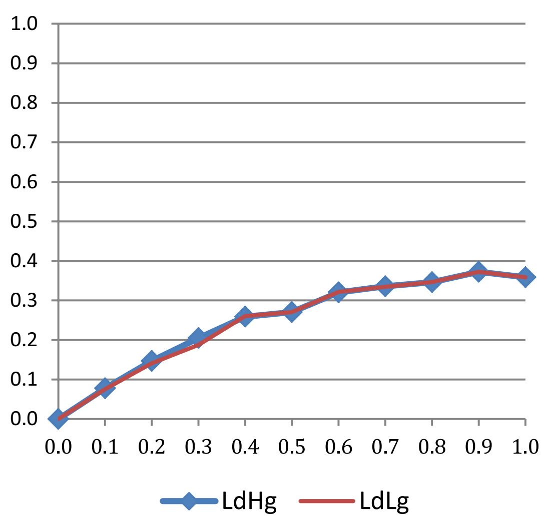

Fig. 8 Comparison of lower diversity with higher granularity results and lower diversity with lower granularity results

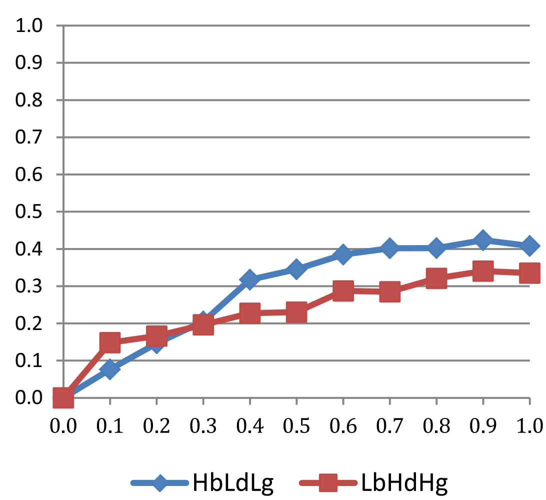

Fig. 10 Comparison of looser budget constraint (higher or more budget) with lower diversity and granularity results and tighter budget constraint (higher or less budget) with higher diversity and granularity results

effect of budget constraint. Moreover, Fig. 10 is specifically generated under the non-linear situation regarding granularity and benefit/risk. For example, if an IT investment project is done to 50%, this project will generate much less than 50% of the original (full size) benefit and risk, such as 25%, but still consume 50% of the original (full size) cost. In other words, this gap between benefit/risk and cost would not happen, when a linear relationship between granularity and benefit/risk is considered. As a result, this gap possibly can explain the dissimilarity between Figs. 5 and 10.

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