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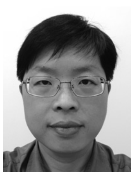
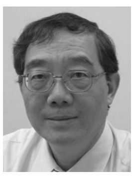

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Abstract

Purpose – *Knowledge has been considered a crucial organizational asset for gaining competitive advantages. It is critical for a firm to maintain a knowledge composition that is productive. This study aims to examine the applicability of the diversity–stability principle in ecology to knowledge management and further investigate the impact of knowledge diversity on firm performance.*

Design/methodology/approach – *A theoretical framework for knowledge diversity and firm performance is proposed; a questionnaire survey was conducted to evaluate the research framework. Fifty-eight valid responses from experts were collected to measure knowledge strength and diversity of 20 enterprises in four industries, and financial indexes of the 20 enterprises from 2008 to 2012 were collected to analyze the research model.*

Findings – *The results show that higher information technology (IT) capabilities in a firm lead to higher levels of knowledge strength and diversity. The strength and diversity of knowledge in a company can improve average company performance and reduce performance variations.*

Research limitations/implications – *This paper presents a new perspective that applies the ecological concept of diversity to examine the value of knowledge in organizations. The findings expand our understanding of the role of IT and knowledge in organizational performance. A limitation is that the sample size is relatively small, which may limit the generalizability of the findings.*

Practical implications – *CEOs and chief knowledge officers can apply the findings herein to assess their organizational knowledge profiles and maintain a healthy knowledge ecology in strategic planning. They should be aware that both knowledge strength and knowledge diversity are crucial to the stability of firm performance.*

Originality/value – *The ecological view of knowledge management stresses the importance of maintaining a healthy intensity and diversity of knowledge at the macro level and indicates a new direction for knowledge management.*

Keywords *Firm performance, Knowledge diversity, Diversity–stability principle, Knowledge ecology*

Paper type *Research paper*

1. Introduction

Recently, knowledge has emerged as an organizational resource for competition. In other words, a knowledge-based view of organizations has gained considerable attention (King, 2007). Successful management of organizational knowledge is considered an essential element for a firm to remain competitive in the new century (Billinfer and Smith, 2001; Migdadi, 2009; Andreeva and Kianto, 2012). Consequently, knowledge management, particularly that based on information technology (IT), has recently received substantial attention (Alavi and Leidner, 2001).

Previous studies in knowledge management have explored perspectives at several levels. A typical perspective that has been adopted by previous studies is the *process view*, in which organizational knowledge management is considered to be a set of "knowledge processes", including creation, storage, retrieval, transfer and application. The process view assumes knowledge to be a generic asset and emphasizes stepwise mechanisms to enhance the knowledge asset competitiveness (Nonaka, 1994; Lee and Choi, 2003). Other

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> **"The data indicate that maintaining a certain level of knowledge diversity is necessary for both IT and knowledge management to be effective in improving firm performance."**

studies have adopted the *resource-based view* to investigate the impact of knowledge assets on organizational performance. Knowledge assets can be the most crucial resource in gaining organizational performance, and knowledge management can further facilitate achieving this goal (Gold *et al.*, 2001; Schiuma, 2012). Other perspectives include the *market view*, which treats knowledge as an asset that may be traded in a market (Grover and Davenport, 2001). In addition, six categories of knowledge perspectives are defined, including knowledge on data and information, state of mind, objects, processes, information access and capabilities. Based on these various knowledge perspectives, different knowledge management strategies are proposed (Alavi and Leidner, 2001).

Although the scope of knowledge management research is increasing rapidly, some critical issues are either yet to be addressed or lack support from empirical evidence. For example, most researchers believe that knowledge management quality affects the performance of a firm (Andreeva and Kianto, 2012; Schiuma, 2012). However, few studies have examined the relationships between these factors. From a management perspective, numerous crucial concerns, such as *whether an organization should focus on a few key categories of knowledge or all knowledge*, remain unexplored. Because knowledge management is a dynamic and continual process, the success of organizations is determined by both the quality of each particular type of knowledge as well as the composition and distribution of several different types of knowledge. It is critical for a firm to maintain a productive and healthy knowledge community. This warrants a new perspective of knowledge management that focuses not on individual activities but on the diversity, balance and interaction of knowledge in organizations. We shall call it an *ecological view* of knowledge management.

Ecology has been applied as a metaphorical term for viewing information systems in organizations (Davenport and Prusak, 1997; Nardi and O'Day, 1999). *Information ecology* in organizations is composed of the people, technologies, practices, values and environment affiliated with that organization. The interactions among these various components provide both macro and dynamic views for studying information systems in organizations. The *knowledge ecology* model portrays the knowledge ecosystem of organizations, defining knowledge distribution, interaction, competition and evolution to describe the structure of knowledge assets in organizations from an ecological view (Chen *et al.*, 2010).

In other academic areas, studies have investigated the effect of knowledge composition and distribution on decision performance. A substantial amount of research on group diversity and performance has been published in recent years (Jehn *et al.*, 1999; Maznevski, 1994; Pelled *et al.*, 1999; Rulke and Galaskiewicz, 2000). The general consensus is that groups whose members have relatively diverse knowledge outperform those whose members are comparatively homogeneous in their knowledge. Positive relationships between top management team heterogeneity and firm performance have also been reported (Carpenter, 2002; Kilduff *et al.*, 2000; McNamara *et al.*, 2002; Pegels *et al.*, 2000). The structural diversity of work groups is crucial to enhancing knowledge sharing with external knowledge sources, which leads to improved group performance (Cummings, 2004). The relationships between the breadth of knowledge sources and innovation success showed that a greater breadth of knowledge sources led to increased revenues for newly commercialized innovations in firms (Leiponen and Helfat, 2010).

These prior works highlight the need to examine the effect of IT and knowledge management on firm performance. In particular, ecological theories can be introduced into knowledge management research as explanatory models, rather than simply being used in the metaphorical sense. An improved understanding of ecological relationships can help organizations develop viable knowledge management strategies (e.g. broad vs focused) to align with their business and IT strategies.

In this paper, we examine the applicability of the diversity–stability theory in ecology to knowledge management. An empirical study of 58 companies in four industries is performed to test the model. The results indicate that knowledge intensity has a positive impact on average performance, whereas knowledge diversity enhances performance stability in firms.

The remainder of this paper is organized as follows: The literature on knowledge management and organizational performance is reviewed in Section 2. The ecological perspective of knowledge management and the relevant literature are introduced in Section 3. The research framework and hypotheses are presented in Section 4. The design of the empirical study and findings are described in Sections 5 and 6, respectively. Finally, Section 7 presents the conclusion and the implications of the findings.

2. Knowledge management and firm performance

In the knowledge economy, knowledge management has played a critical role in advancing organizational performance. Activities entailing knowledge management processes, such as knowledge acquisition, transfer and creation, improve organizational processes directly and lead to enhanced organizational performance (King, 2007; Andreeva and Kianto, 2012). Because knowledge has been the most crucial competitive asset in organizations, numerous previous studies have discussed the relationship between knowledge management and organizational performance.

From a knowledge capability perspective, knowledge infrastructure and knowledge processes support organizational performance (Gold *et al.*, 2001). Four types of knowledge management enabler in organizations have been proposed: culture, structure, people and IT. These knowledge management enablers facilitate the knowledge management process and organizational creativity (Lee and Choi, 2003), additionally improving organizational performance. Furthermore, knowledge management capability has a direct influence on organizational performance, and IT relatedness enhances organizational knowledge management capability (Tanriverdi, 2005).

Aside from the direct impact of knowledge management on organizations, some prior studies have identified indirect effects in this relationship that are caused by mediating factors. The knowledge creation process should align with near-term tasks first, enabling organizations to yield maximal returns. Organizations can benefit from aligning knowledge management skills with tasks (Chen and Edgington, 2005). The assurance of knowledge quality in knowledge repository systems evidences the importance of knowledge-validating mechanisms in organizations. Knowledge validation inspires knowledge contribution and enhances organizational performance (Durcikova and Gray, 2009). Generalized and contextualized knowledge support in software development projects has been explored in previous studies, which found that knowledge support assists in enhancing the efficiency and effectiveness of the software-building process (Xu and Ramesh, 2008).

"Higher knowledge intensity improves the average performance of a firm but reduces performance stability."

> **"Different industries seem to have different keystone knowledge types."**

Regardless of whether knowledge has a direct or indirect impact on organizational performance, knowledge has clearly played a critical role in business management. In this paper, we investigate the relationships between knowledge assets and organizational performance based on ecological theories. Ecological theories are distinct from traditional theories because they provide a macro view for studying knowledge in organizations and create new insights for knowledge management.

3. An ecological framework for knowledge management

Ecology is a science in which relationships among members of a community and their interactions with the environment are analyzed. The essential components of an ecological community are the various species and the materials exchanged between the species and the environment. Within an ecosystem, there are two major streams of focus: population ecology, which concerns evolution and change in species, and community ecology, which concerns diversity and balance in the species of a community (McGlade, 1999). Various elements within an ecosystem coevolve: they change together on the basis of their relationships within the system. This is similar to knowledge in organizations: various types of knowledge coevolve to build organizational core competence.

3.1 Ecological analogy of knowledge management

Ecological models were first applied to organizations in the 1980s. An ecological view of organizational growth was proposed; it:

> [. . .] seeks to understand how social conditions affect the rates at which new organizations and new organizational forms arise, the rate at which organizations change forms, and the rates at which organizations and forms die out (Hannan and Freeman, 1989).

In the mid-1970s, most theories and research treated organizations as rational, flexible and rapid adapters to changing environments. Therefore, unpredictability in structures was accounted for by local adaptations to short-term environmental fluctuations.

Similarly, knowledge ecology comprises various areas of knowledge in organizations, such as marketing, manufacturing and research and development (R&D). People possess the knowledge, technology and tools that facilitate the flow of information and knowledge. Knowledge is exchanged through knowledge sharing mechanisms, which may be supported by IT and other technologies. Core competence is based on the composition, distribution, interaction and integration of different areas of knowledge in the organization. The goal of organizational knowledge management is to build a mechanism that can maintain a healthy balance of knowledge to achieve superior performance (Chen *et al.*, 2010).

The various areas of knowledge in an organization represent different species working together to optimize the survivability of the ecology in a given economic environment. Because organizational decisions often result from collective processes, knowledge in a particular area may be possessed by multiple experts in the organization and may exist in both tacit and explicit forms. This is distinct from organizational ecology, in which different forms of organizations represent species; the main concern in organizational ecology is the behavior of organizations within an economic society, whereas the main concern in knowledge ecology is the role of various types of knowledge in organizations. Therefore, the level of analysis in each ecology type is distinct.

3.2 Key issues in knowledge ecology

Several key aspects exist in the ecological analysis of organizational knowledge. One aspect of particular importance is the *diversity–stability relationship*, which is the relationship between the diversity of life forms occupying ecosystems and the behavior of those systems. This concept encompasses questions regarding how species coexist and how communities of populations influence ecosystem performance. Early theoretical discussions established the axiom that the most diverse, complex ecological communities are the most stable (Frank and McNaughton, 1991; Johnson *et al.*, 1996; Tilman *et al.*, 1996, 1998; Doak *et al.*, 1998). Although some previous studies have attempted to challenge the universality of the diversity–stability paradigm (Gardner and Ashby, 1970; May, 1972, 1974), a substantial body of recent ecological studies has provided compelling evidence that diversity promotes stability in ecosystems by buffering them against natural and artificial perturbations. Diversity also increases system productivity (Smith, 1996). When the diversity–stability theory is applied to knowledge management, we may presume that a higher diversity in organizational knowledge may facilitate maintaining stability in organizational performance.

A second aspect of the ecological analysis comprises *keystone species.* An ecosystem is marked by the presence of keystone species crucial to the survival of the ecosystem itself (Nardi and O'Day, 1999). Its implication for knowledge ecology is that analyzing keystone knowledge crucial to the survival of the organization may be critical and that knowledge management may need to emphasize the identification and maintenance of keystone knowledge.

A third key aspect of the ecological analysis comprises the *coevolution and niches of species* in an ecology. Species tenaciously migrate and adapt to fill available niches. These adaptations reflect a continuous evolution as the entire system adjusts to new constraints and possibilities. A healthy ecology is not static but exists in a dynamic equilibrium. Differential knowledge among species causes coopetition in an organization and leads to the coevolution of knowledge (Carayannis *et al.*, 2014). For knowledge management, this can be applied to improve the analysis of knowledge creation and enhancement processes. The evolution of knowledge and its interactions in various domains may be analyzed to determine its relationship to firm evolution and performance.

Finally, the ecological model also enables the analysis of the *knowledge web*: the relationship and interaction of knowledge. The niche theory in the ecological analysis assumes that various species play different roles to form a food web in ecosystems. For instance, most natural ecologies have producers (e.g. grass), consumers (e.g. goats, who eat grass) and a feedback mechanism. Similarly, various types of knowledge in a knowledge ecosystem may play different roles in building a knowledge web. For instance, knowledge of IT may facilitate the enhancement of other knowledge types, serving as a facilitator, whereas marketing and manufacturing knowledge serve as producers that receive orders and deliver products. Because various firms may have different strategies, a single type of knowledge may serve various roles in different knowledge ecologies. This may also partially explain why certain companies are more marketing-oriented, whereas others may be more manufacturing-oriented.

"Higher knowledge diversity reduces the average performance of a firm but increases performance stability by reducing EPS variations."

3.3 Effect of knowledge ecology

The ecological model of organizational knowledge may have a substantial impact on certain research paradigms in knowledge management. For instance, the model may enhance the current research paradigm of IT and firm performance, in which researchers use IT investment or capabilities as independent variables to examine their impact on firm performance (Li and Ye, 1999; Bharadwaj, 2000; Sircar *et al.*, 2000). Concerning IT capabilities and firm performance, the existing model can measure whether IT has an effect on performance but fails to explain why such an effect exists.

Through knowledge ecology, we can apply knowledge diversity as an intervening variable. In other words, IT capabilities affect firm performance through their effect on knowledge ecology. This argument is not entirely new. For instance, IT systems create advantages by transforming firm-specific knowledge into specialized assets that are almost impossible for competitors to imitate (Bharadwaj, 2000). The role of IT in organizations is to support the exploitation of knowledge and facilitate dialogue among highly differentiated experts (Tenkasi and Boland, 1996). Our framework extends the development of empirically testable theories that allow IT performance research to link with knowledge management research.

4. Research framework and hypotheses

In this section, a research model based on the diversity–stability theory is developed to link the relationships among IT capabilities, knowledge ecology and firm performance. As shown in Figure 1, the research model has two stages. The first stage exhibits the relationship between IT capabilities and knowledge ecology. Here, knowledge ecology is represented as the *strength* and *diversity* of knowledge in an organization. The second stage presents the relationship between knowledge ecology and firm performance. There are several ways to measure firm performance. In this research, we focus on financial performance, represented by the average earnings per share (EPS) and their variations. Performance variation is represented as negative performance stability in firms. A firm with higher variation has lower stability.

4.1 Roles of IT in knowledge management

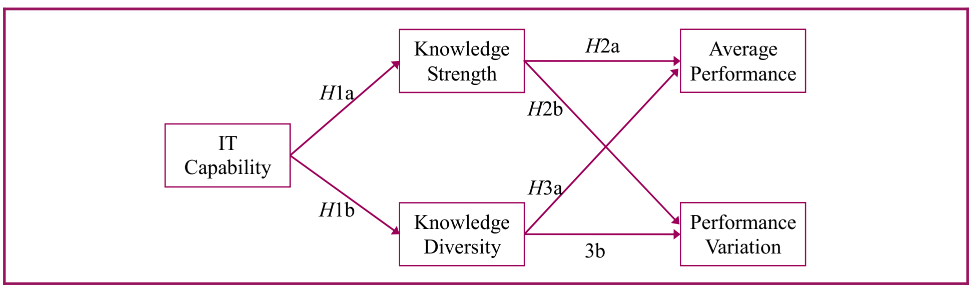
First, IT capabilities have long been considered a critical asset for facilitating knowledge management. An effective IT infrastructure allows knowledge to be stored, created and shared more efficiently (Alavi and Leidner, 2001; Tanriverdi, 2005; Wang *et al.*, 2015). Therefore, it is plausible that firms with IT capabilities that are more effective support a higher level of knowledge strength and are more capable of handling knowledge diversity. Hence, the first set of hypotheses is as follows:

H1. Relationship between IT and knowledge ecology.

H1a. Higher IT capabilities support higher levels of knowledge strength.

H1b. Higher IT capabilities support higher levels of knowledge diversity.

Figure 1 Research model



4.2 Effect of knowledge strength

The second relationship in the research model is that between knowledge strength and firm performance. Given that knowledge is a critical asset for competitiveness, we assume that firms with higher knowledge strength yield higher average performance and less performance variation (Gold *et al.*, 2001; Ho, 2009; Andreeva and Kianto, 2012; Tan and Wong, 2015):

H2. Relationship between knowledge strength and firm performance.

H2a. Firms with higher knowledge strength yield higher average performance.

H2b. Firms with higher knowledge strength yield lower performance variation.

4.3 Effect of knowledge diversity

Diversity refers to the distribution of various species in a community, and it reflects the degree of equitability among the species of that community (Bidwell and Kasarda, 1985). If the diversity is high (i.e. equitability degree is high), the structure of the community is usually stable and can more effectively handle fluctuations in the external environment. In fact, knowledge diversity has been found to have an effect on performance in numerous organizational aspects. For instance, information diversity among working groups, as mediated by a few other factors, positively influences group performance (Jehn *et al.*, 1999), and the functional diversity of a work group has a positive effect on task performance (Pelled *et al.*, 1999). In the management literature, top management team heterogeneity is demonstrated to be positively correlated with firm performance (Kilduff *et al.*, 2000; Carpenter, 2002; McNamara *et al.*, 2002; Pegels *et al.*, 2000). Therefore, we can hypothesize the following:

H3. Relationship between knowledge diversity and firm performance.

H3a. Firms with higher knowledge diversity have higher average performance.

H3b. Firms with higher knowledge diversity have lower performance variation.

5. Design of the empirical study

To test the research model, an empirical study using a focus group of 58 experts was conducted on 20 firms in four industries. Industry type is a crucial factor in research on organizational knowledge management (Cheng *et al.*, 2014). To investigate the moderating effects of industry type, four industries were chosen to represent different organizational natures along two dimensions: knowledge intensity of products or services and environmental uncertainty. Because knowledge may include several different types of intangible asset, the knowledge intensity of products is measured by the ratio of the intangible portion of the total revenue in financial statements: (total revenue − tangible costs)/total revenue. For example, if the total revenue of a firm is 100 million and the total tangible cost (including materials, equipment depreciation and other fixed assets) is 70 million, then the knowledge intensity of its product is 0.3. Environmental uncertainty is measured by the degree of product deviation and average product life cycle. An industry whose product life cycle is short implies a higher environmental uncertainty. For instance, the environmental uncertainty of a PC manufacturer is higher than that of a steel company because PCs have a much shorter product life cycle than steel does.

On the basis of the aforementioned criteria, the integrated circuit (IC) design, semiconductor foundry, banking and steel industries were chosen (Table I). In each category, five companies listed on the Taiwan Stock Exchange or NASDAQ were selected.

5.1 Variable measurements

5.1.1 Defining knowledge areas. There are several ways to differentiate knowledge (e.g. tacit vs explicit; qualitative vs quantitative); however, few studies have examined which knowledge domains are essential for organizational operations. A straightforward approach is to categorize knowledge by business activities in the value chain. This is reasonable because a common practice for recruiting and training is to classify knowledge by functional areas, such

Table I Research model

		Environmental Uncertainty	
Knowledge intensity of products		*Low*	*High*
	High	Banking	IC design
	Low	Steel	Semiconductor foundry

as selection and preparation of raw materials, food processing, preservation and packaging in the food processing industry (Smith, 2002). Following this philosophy, we define 12 major areas of knowledge: raw material acquisition, production and manufacturing, distribution and logistics, marketing and channels, customer services, strategic planning and new business development, general management, financial management, quality management, human resource management, research and development and IT applications.

Because various industries differ in certain aspects, some knowledge areas are further tailored to the industries' unique characteristics. For IC design, raw material acquisition is changed to "component acquisition" because the major raw material is the IC component for design, and distribution is changed to "product management" because management of the resulting design is the most critical function after production. For banking, research and development is focused on designing new financial product, and the term "product design" is therefore applied; raw material acquisition is termed as "capital acquisition" because capital is the raw material in banking. Furthermore, because the major operation in banks is asset management, production and manufacturing is termed as "asset management".

5.1.2 Knowledge strength and diversity. Given the 12 areas of knowledge, the strength of IT capabilities and other 11 knowledge areas is assessed using a seven-point Likert-scale questionnaire. Therefore, the knowledge strength and IT capabilities of a firm are assessed by our experts, ranging from 1 (the worst) to 7 (the best). The knowledge strength of a firm is the mean of the 11 knowledge areas, not including IT capabilities. A higher value indicates a higher knowledge quality compared with firm competitors.

There are several possible measures of diversity in ecology. To retain both the ecological richness and evenness of the information, we use the Shannon–Wiener index (called "entropy", and is often denoted as "H"), which is the most popular diversity index in ecological research (Krebs, 1999). Entropy is defined as $H = -\sum_{i=1}^{n} p_i \ln p_i$, where p_i is defined as (number of species *i*)/(number of total species). Here, p_i is defined as the strength of a knowledge area divided by the sum of the strength of all 11 other knowledge areas. For example, if the knowledge strength of marketing is 5 on the seven-point scale and the total knowledge strength of the other 11 knowledge areas is 30, then the p value of marketing knowledge is 0.17. The entropy can then be calculated from the aforementioned equation. A higher entropy value implies greater diversity (i.e. more balanced distribution) in the knowledge community.

5.1.3 Firm performance. Firm performance is measured by financial performance (Ho, 2009). Among various financial measures, we use EPS. This is because EPS can effectively indicate the return for the shareholder. EPS data from a five-year period (2008–2012) were collected for analysis. Overall performance is the average EPS for the five-year period, and performance variation is the EPS deviation in the five-year period.

5.2 Focus group survey

A group of experts agreed to participate in the study. The experts were asked to complete a questionnaire and were interviewed over the phone to ensure the reliability of their assessments. These experts had an average of more than five years of work experience in their respective industries and were generally knowledgeable of the relative strengths and weaknesses of the sample companies. Table II shows the profiles of their educational backgrounds and their positions at the time of the survey.

The questionnaire consists of two parts. The first part assesses the relative importance of various knowledge areas in the industries. The second part assesses the relative strength of different knowledge areas (identified based on activities in the value chain) among five companies in each industry. Fifty-eight responses were collected from the selected experts, among which 17 were from the semiconductor industry, 16 were from IC design houses, 15 were from banks and 10 were from firms in the steel industry.

6. Analysis of results

6.1 Difference in knowledge importance

The first question we investigate is whether the relative importance of key knowledge differs among industries. As shown in Appendix 1, except for R&D, the top three or four knowledge areas ranked by the experts differ among industries. For instance, IC design houses require knowledge on component acquisition (raw material), whereas banks require knowledge on asset management (production). Therefore, if it is critical for knowledge management to support major knowledge activities, then the focus of knowledge management may differ among industries.

Another observation is that IT knowledge ranks low in most organizations; IT application knowledge did not rank among the top five knowledge categories crucial to firm survival. Although this is may be unfavorable for IT researchers, this may represent the view of functional managers outside IT divisions, that IT is capable of supporting other knowledge types for strategic competition but may not directly affect performance. This is consistent with our model (Figure 1); the impact of IT on performance occurs through its effect on the intervening variable of *knowledge ecology*.

6.2 Hypothesis testing

Before testing the hypotheses, Cronbach's α was used to verify the reliability of the expert assessments; Table III presents the result. Because α values below 0.6 are considered unacceptably low, financial management in the IC design industry, quality management in the semiconductor industry and customer services in the banking industry were removed for further analysis.

A path analysis of all observations was conducted to test the hypothesis. The results shown in Figure 2 indicate that all three sets of hypotheses hold. For *H1*, IT capabilities positively correlate with knowledge strength and diversity, with coefficients of 0.740 and 0.414 (both $p < 0.001$), respectively. This implies that higher IT capabilities in a firm lead to higher levels of knowledge strength and diversity, and both *H1a* and *H1b* are supported.

For *H2*, knowledge strength has significantly positive effects on firm performance (0.619, $p < 0.001$) and performance variation (0.502, $p < 0.001$). In other words, higher knowledge

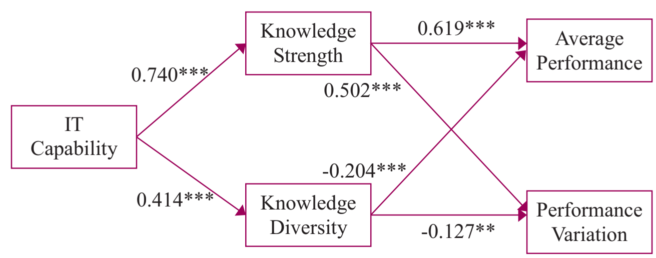
Table II Profile of the responding subjects

		Highest degree		Position		
Industry	*Total*	*Bachelor*	*Master*	*Manager*	*Engineer/ officer*	*Professional consultant*
Semiconductor	17	2	15	1	14	2
IC design	16	2	14	0	15	1
Banking	15	6	9	7	5	3
Steel	10	7	3	0	9	1

Table III Reliability Cronbach's α of expert responses

Knowledge areas	*IC design*	*Semiconductor foundry*	*Banking*	*Steel*
Raw material acquisition	0.8977	0.8608	0.7274	0.7401
Production	0.7180	0.7686	0.7921	0.8023
Distribution	0.7901	0.9489	0.7407	0.9265
Marketing	0.6600	0.8357	0.7096	0.8247
Customer services	0.8008	0.7446	*0.1027*	0.7342
Strategic planning	0.6704	0.6390	0.8388	0.8106
General mgt.	0.7866	0.8625	0.8415	0.7020
Finance mgt.	*0.5080*	0.7869	0.8711	0.7803
Quality mgt.	0.7961	*0.5822*	0.9249	0.8780
Human resources mgt.	0.7750	0.7334	0.9120	0.8691
R&D	0.7709	0.8471	0.8013	0.6753
IT applications	0.9392	0.7617	0.9130	0.8231
All constructs	0.9576	0.9459	0.9508	0.9627

Figure 2 Results from the path analysis



Notes: ***Significance at the 0.001 level; **significance at the 0.01 level

strength tends to generate higher average EPS (which is favorable, *H2a* is supported) and higher EPS variation (which is unfavorable, *H2b* is rejected).

For *H3*, knowledge diversity has significantly negative effects on firm performance (−0.204, $p < 0.001$) and performance variation (−0.127, $p < 0.01$). Therefore, higher levels of knowledge diversity reduce the average performance (which is unfavorable, *H3a* is rejected) but increase performance stability (which is favorable, *H3b* is supported) by reducing performance variations.

Overall, the path analysis shows that *IT capabilities are useful in maintaining the strength and diversity of knowledge in a company, which in turn can help improve the average performance and reduce performance variations.*

We also ran the path analysis on the four industries. The results, as shown in Table IV, indicate that the effect varies among the industries. Four of the six hypotheses are insignificant for banks. In general, the effect between IT and knowledge ecology (*H1a* and

Table IV Analysis by industry

Industry \ *Hypotheses*	H1a	H1b	H2a	H2b	H3a	H3b
IC design	0.675***	0.326**	0.630***	0.565***	ns	−0.125*
Semiconductor	0.718***	0.375***	0.732***	ns	−0.375***	−0.195*
Banking	0.621***	0.436***	ns	ns	−0.283*	−0.272*
Steel	0.724***	0.364***	0.502***	−0.351*	−0.429**	ns

Notes: ***Significance at 0.001; **significance at 0.01; *significance at 0.05; ns, not significant

H1b) is significant in all cases. The effects of knowledge strength on average performance (*H2a*) are supported in all industries except banking; this result means that knowledge strength is crucial for firm performance in most industries. Knowledge strength has a positive influence on performance variation in the IC design industry and a negative effect in the steel industry (*H2b*). This result implies that the firms in different industries should adopt knowledge management strategies to maintain a healthy knowledge ecology to enhance competitiveness.

The knowledge diversity can reduce performance variation in IC design, semiconductor and banking (*H3b*). This hypothesis is only not supported in the steel industry. That might be because the performance variation is not significant all the time in the steel industry; therefore, we cannot find significant statistical support. Knowledge diversity might also cause negative impacts on average performance (*H3a*). In these cases, the knowledge management strategy should focus on only a few major knowledge areas.

6.3 Sensitivity analysis

Whether changing the spread of the knowledge areas would have an effect on the model is worth considering. The analysis was conducted for all 11 types of knowledge (not including IT capabilities); we ran a stepwise analysis whereby one knowledge area, deemed the least crucial by the experts (as shown in Appendix 1), was removed at a time. The same path analysis was repeated nine times (decreasing from 11 knowledge areas to three areas). The results are summarized in Table V. The top row represents the coefficients of the 11-area model in Figure 2. As shown in Table V, the model holds for most situations; however, the diversity hypothesis, *H3*, becomes insignificant when the number of knowledge types under study is below four. This is reasonable because diversity becomes insignificant when the number of knowledge areas is insufficiently low.

The data in Table V indicate that maintaining a certain level of knowledge diversity is necessary for both IT and knowledge management to be effective in improving firm performance. The correlation coefficients decrease slightly between the top 11 and the top 3 for *H1a*, implying that the effect of IT capabilities decreases as the number of knowledge areas decreases. Firms that use IT to support knowledge activities in all 11 areas are more likely to generate higher knowledge than those using IT to support only three knowledge areas. The generally declining trend in correlation coefficients also holds for *H2a*, *H2b*, *H3a* and *H3b*, implying that the effect of knowledge strength and knowledge diversity on firm performance decreases as the number of knowledge areas maintained by a firm decreases. Because the largest coefficients often do not occur in the first row (all 11 knowledge areas), firms emphasizing all knowledge areas equally may not have the greatest impact.

Table V Coefficients of the model under different spread of knowledge

Knowledge \ *Hypotheses*	H1a	H1b	H2a	H2b	H3a	H3b
Top 11	0.740***	0.414***	0.619***	0.502***	−0.204***	−0.127**
Top 10	0.719***	0.387***	0.617***	0.505***	−0.195***	−0.137**
Top 9	0.743***	0.422***	0.603***	0.499***	−0.192***	−0.155*
Top 8	0.700***	0.365***	0.602***	0.514***	−0.183**	−0.170**
Top 7	0.711***	0.368***	0.635***	0.511***	−0.196***	−0.157*
Top 6	0.699***	0.338***	0.636***	0.510***	−0.163**	−0.145**
Top 5	0.697***	0.339***	0.608***	0.477***	−0.162**	−0.142*
Top 4	0.705***	0.322***	0.535***	0.433***	ns	ns
Top 3	0.669***	0.184**	0.491***	0.392***	ns	−0.154**

Notes: ***Significance at 0.001; **significance at 0.01; *significance at 0.05; ns, not significant

6.4 Difference in key knowledge

Given the various effects of knowledge ecology on firm performance, we may further examine whether key knowledge differs among industries; stepwise analysis on data of individual industries was performed. Table VI shows the results of *H2a* (i.e. effect of knowledge strength on the average performance of a firm) for the four industries. The steel industry has 11 more knowledge areas for analysis than the other three industries because they each had one knowledge area removed, owing to low data reliability.

The model that shows the greatest impact of knowledge strength on firm performance comprised five knowledge categories for the IC design, three categories for the semiconductor and four categories for the steel industry. In other words, the number of knowledge areas that must be managed differs among industries. For the banking industry, no significant relationship exists between knowledge strength and average firm performance, which was an unexpected result. We suspect that this resulted from the highly regulated nature of the banking industry. The similar knowledge strength among various banks renders it an insignificant factor.

7. Discussion

In this paper, we propose an ecological approach to knowledge management in organizations, which stresses the importance of maintaining a healthy intensity and diversity of knowledge at the macro level rather than examining the creation, storage and transfer of knowledge at the micro level. Our empirical study shows that IT capabilities can enhance both the intensity and the diversity of knowledge. Higher knowledge intensity improves the average performance of a firm but reduces performance stability. However, higher knowledge diversity reduces the average performance of a firm but increases performance stability by reducing EPS variations. Different industries also seem to have different keystone knowledge types.

Table VI Key knowledge categories among industries

Hypotheses / *Knowledge category*	*IC design*	*Semiconductor*	*Banking*	*Steel*
Top 11	–	–	–	0.502***
Top 10	0.594***	0.535***	ns	0.496**
Top 9	0.599***	0.543***	ns	0.510***
Top 8	0.587***	0.573***	ns	0.503***
Top 7	0.612***	0.571***	ns	0.505**
Top 6	0.612***	0.600***	ns	0.539***
Top 5	0.620***	0.601***	ns	0.565***
Top 4	0.550***	0.604***	ns	0.587***
Top 3	0.541***	0.659***	ns	0.540***
Top 2	0.412***	0.627***	ns	ns
Top 1	0.294**	0.483***	ns	ns

Notes: ***Significance at 0.001; **significance at 0.01; ns, not significant

Table VII Direct effect between IT and firm performance

Industry	*Average performance*	*Performance variations*
All industries	0.318***	0.308***
IC design	0.275*	0.282*
Semiconductor	0.478***	ns
Banking	ns	ns
Steel	0.275*	ns

Notes: ***Significance at 0.001; *significance at 0.05; ns, not significant

The correlation coefficients of direct effect between IT and firm performance are shown in Table VII. As the results show, the overall effects of IT capabilities on average performance and performance variation are both positive. In other words, higher IT capabilities result in higher EPS and EPS variations. This is consistent with our findings regarding the relationship between knowledge strength and firm performance; however, our previous model contains a substantially greater quantity of information for explaining the relationships among IT capabilities, knowledge ecology and firm performance.

8. Conclusion

The findings of this paper expand those of previous research on IT values and knowledge management by introducing the dimensions of knowledge strength and diversity. Knowledge ecology is shown to be an effective intervening variable between IT capabilities and firm performance, serving as a new paradigm for performance-related research. The results also provide a new knowledge management concept for managers. An organization should maintain a balanced strategy between knowledge intensity and diversity for sustainable development. An effective knowledge management strategy should focus on more than just a few specific knowledge assets by maintaining a balance among different knowledge assets. In other words, managers should compose knowledge management strategies at the macro rather than the micro level.

Because of the exploratory nature of this study, several limitations may exist. First, only four industries are covered in the study. The generalizability of the findings may require a comprehensive examination of other industries and the addition of more companies to the sample. Second, whether culture affects the value of the framework is unclear. Although most firms in the study are internationally ranked (e.g. the Taiwan Semiconductor Manufacturing Company is one of the largest in the world, with securities traded on the New York Stock Exchange), it is still possible that different national cultures and economic environments may cause different results. Even with the possible limitations, this paper reveals a new and promising perspective for analyzing knowledge management. Further ecological hypotheses and concerns related to the idiosyncrasies of individual industries should be formulated and investigated in the future.

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Appendix

Table AI Importance rankings of knowledge areas in different industries

	IC Design		*Semiconductor*		*Bank*		*Steel*	
Knowledge type	*Mean*	*Rank*	*Mean*	*Rank*	*Mean*	*Rank*	*Mean*	*Rank*
R&D	6.69	1	6.71	1	6.27	1	6.40	1
Raw material acquisition	6.56	2	5.41	10	5.73	5	5.90	9
Strategic planning	6.50	3	6.06	4	5.60	7	5.80	11
Production	6.44	4	6.35	2	6.13	2	6.20	3
Marketing	6.19	5	5.47	8	5.80	3	5.80	12
Quality mgt.	6.19	6	5.88	5	5.20	9	6.30	2
Distribution	5.94	7	4.71	12	4.87	11	6.20	4
IT applications	5.69	8	5.82	6	5.53	8	5.80	10
Customer services	5.69	8	6.18	3	5.80	4	6.00	7
General mgt.	5.63	10	5.65	7	5.67	6	6.10	6
Human resources mgt.	5.63	10	4.82	11	4.53	12	6.00	8
Finance mgt.	5.44	12	5.41	9	5.20	10	6.20	5

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