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92. Analyzing and Testing Knowledge Management Complementarity Structures

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Abstract

Recent research on firm level productivity and organizational performance has highlighted the importance of complementarity among organizational practices. A number of studies have developed methods to test the existence of complementarity among such organizational variables. However, despite these advances in the study of industrial organization and management, our understanding of the complementarity structures remains sketchy. In this paper, we seek to advance research on this topic by identifying different classes of complementarity structures and developing a testing procedure for each class. A three-level testing procedure is developed to find complementarity structures which can be categorized into four different classes: non-complementarity, critical complementarity, non-critical asymmetric complementarity, and non-critical symmetrical complementarity. The testing method is illustrated by using an empirical illustration of a range of knowledge management (KM) strategies as they impact on knowledge creation processes in organizations.

Keywords: Organization Analysis and Knowledge, Complementarity Theory, Constrained Regression

Introduction and Motivation

The importance of developing a good understanding of the diverse interactions and interrelatedness among sets of organizational factors as they impact on performance is widely acknowledged. Changing one factor may have little effect if other factors remain unchanged. Understanding these complex relationships is central for a range of disciplines such as organizational studies, information systems, and economics. For example, researchers in the fields of industrial organization and management have long been interested in investigating whether complementary relations been various organizational practices can be shown to exist. The theory of complementarity provides an avenue to explain not only the direct impact of one factor on the expected outcome but also provides a way to capture the intuitive ideas of synergy and system effects (Athey and Stern 1998), i.e. “the whole is more than the sum of it parts.” Furthermore, it constitutes the starting point for exploring the limitations of reductionism perspectives (Huang et al. 2004).

The concept of “complementarity” was first introduced by Edgeworth (1881) in which he defined activities as complements if doing (more of) any one of them increases the returns to doing (more of) the others. Milgrom and Roberts (1990, 1995) proposed that some organizational activities and practices are mutually complementary and so tend to be adopted together, with each enhancing the contribution of the other. Therefore, the impact of a system of complementary practices will be greater than the sum of its parts because of the synergistic effects of bundling practices together.

Many researchers have investigated complementary relationship among various business practices. For example, Black and Lynch (2001) found evidence of synergies among various workplace practices and concluded that the important issue is not whether an organization adopts a particular work practice but rather how that work practice is implemented in conjunction with other complementary practices. Bresnahan et al. (2002) surveyed approximately 400 large firms to obtain information on various aspects of organizational structure and found that these work practices were correlated with each other. Both studies argued that these practices were part of a complementary system.

Previous studies have contributed to our understanding of whether and how complementary relationships among organizational practices lead to significant increases firm-level productivity or performance. However, the model construction for empirical testing is still a critical problem in studying complementarities due to three broad reasons. First, complementary factors need to be considered simultaneously. Second, the levels of impacts can vary significantly between different configurations. Third, there can be many possible complex forms of relationship structure among the complementary factors. In sum, many of the empirical analyses assessing complementarities have suffered from a lack of specificity in conceptualizing the relationship structure among potential complementary factors. This is due to the fact that model construction requires identification of potential input factors, in addition to the relationship structure of those potential factors. Therefore, there is a need to model the complex inter-relationship structures of the potentially complementary factors. The aim of this paper is to address this important issue.

This paper is organized as follows: In section 2, we present a literature review and the theoretical basis of our analytical approach. We describe our methodology in section 3. Section 4 provides an example using KM practices data in order to evaluate our framework. Section 5 concludes the paper.

Theory of Complementarity

Complementarity and Supermodularity

The notion of complementarity requires only that some order relation be put on the objects under consideration. This observation has led to the actual formalization of the concept in the mathematical theory of lattices, which is the basis for the development of monotone optimization problems pioneered by Donald Topkis (Topkis 1978). This concept of "complementarities" offers a useful perspective to study the complex relationships among a set of organizational practices as they impact on performance.

By drawing on lattice theory and supermodularity[5], Milgrom and Roberts (1990, 1995) marked the starting point for the renewed interest in the role of organizational complementarities. They proposed the "*web of complementarities*" theory which marked an important new direction for research. They argued that some of the organizational activities and practices are mutually complementary and so tend to be adopted together, with each enhancing the contribution of the other.

The notion of complementarities discussed here can be represented by the "supermodularity" of a function with respect to two or more complementary variables (Topkis 1978).

[5] Given a real-valued function f on a lattice X, we say that f is supermodular and its arguments are complements if and only if for any x and y in X, $f(x)-f(x \wedge y) \leq f(x \vee y)-f(y)$

Supermodularity dictates that the sum of the increases in the value of a function when the levels of the complements are changed one at a time would be less than the increase in the function's value when the levels are changed simultaneously. If complementarities among activities exist, then the gains from increasing every component are larger than the sum of the individual increases. In other words, a test for complementarities must consider performance data on some function that is hypothesized to be supermodular.

Suppose there are two organizational practices P_1 and P_2. Each practice can be carried out by the firm (P_1=1) or not (P_1=0) and (P_2=1) or not (P_2=0). The function $\Pi(P_1, P_2)$ is supermodular and P_1 and P_2 are complements only if: $\Pi(1,1) - \Pi(0,1) \geq \Pi(1,0) - \Pi(0,0)$, i.e. adding an activity while already performing the other practices has a higher incremental effect on performance Π than when doing the activity in isolation. Even though the concept of complementarities offers a set of important implications for analyzing business value, there are no known methods to conceptualize the complex relationships between P_1 and P_2.

Essentially, complementarity theory is about "fit". This theory has many similarities to the contingency theory and the configuration theory (Whittington et al. 1999). Firstly, contingency theory considers performance as dependent on the fit between organizational variables (Schoonhoven 1981). This theory enables us to investigate the specified theoretical relationship among the distinct organizational practices which are considered to be mutually-independent (Huang et al. 2004) and are often conceptualized as pair-wise co-alignment (Venkartraman and Prescott 1990).

Secondly, configuration theory builds on contingency theory by taking a holistic view of organizational practices and their relationships (Ketchen et al. 1993). The basic assumption of this theory is that meaning creation is the result of the dynamic interplay among individual parts and the whole of any social entity such as an organization. Social entity as a whole cannot be understood in isolation. Rather than trying to explain how order is designed into the parts of an organization, configurational theorists try to explain how order emerges from the complex interactions of those parts as a whole (Meyer et al. 1993).

Complementarity theory takes both a holistic view of organizational practices and focuses on the interdependence of fit in bundles of practices. Unlike the contingency theory, complementarity theory assumes that separate variables cannot be individually fine-tuned to achieve better performance (Huang et al. 2004). Unlike the configuration theory, complementarity theory focuses on uniqueness rather than the general archetypes that are in common in research using configuration theory (Whittington et al. 1999). The effects of complementarity on performance have been explored empirically (Ichniowski et al. 1997) and can be used to provide more operational insights into the nature of change involved (Barua et al. 1995, Huang et al. 2004). For example, Milgrom and Roberts insisted that "changing only a few of the system elements at a time to their optimal values may not come at all close to achieving all the benefits that are available through a fully coordinated move, and may even have negative payoffs (Milgrom and Roberts, 1995, p. 191)."

Essentially complementarity theory recognizes the potential uniqueness of the complementary relationships among organizational practices, the challenge for us is to develop appropriate methods to model the complementary relationships between the potentially synergetic practices. There could be several possible relationship structures among complementary practices that can lead to supermodularity. The problem is to identify an appropriate relationship structure to be hypothesized, and then to find appropriate statistical model which will allow the testing of supermodularity.

Milgrom and Roberts (1990, 1995), the pioneers of complementarity theory in economics, provided two key insights for this study. First, at the conceptual level, they highlighted the importance of complementary activities for explaining the adoption of new organizational structure. Second, at the application level, their papers built on the works of Topkis (1978) to provide a mechanism to explain a condition that there are increasing returns when the level of complementary activities is increased simultaneously. Therefore, analysis of complementarities requires us to hypothesize and test if the performance function is supermodular - that is, function comprising potential complements is hypothesized to exhibit a relationship of increased returns.

Review of Complementarity Testing Methods

Athey and Stern (1998) argued that testing for complementarity can be achieved in two different ways. One approach is based on correlation among organizational practices. Many empirical researchers have used this correlation approach due to its simplicity (Arora 1996). This approach tests conditional correlations based on the residuals of reduced form regressions of the organizational practices on observable exogenous variables (Holmstrom and Milgrom 1994). Colombo and Mosconi (1995) applied a similar method and found complementarities between the application of new process technology and organizational innovations. Similarly, Arora and Gambardella (1990) used the correlation of residuals method and found that certain strategies of large chemical and pharmaceutical producers were indeed complementary. However, although this method can provide a useful way of analyzing complementarity between practices statistically, it cannot serve as a definitive test. Estimated correlations between residual terms may be the result of common omitted exogenous variables or measurement errors. Even though there is reliable correlation between practices, it does not guarantee that combinations of the practices lead to enhanced output (Lokshin et al. 2004). Furthermore, this approach is not able to disentangle interactions between more than two variables (Arora 1996, Mohnen and Roller 2005).

A second approach based on production function regresses a measure of productivity on a set of regressors, including the interaction effect, the coefficients of the interactions can be viewed as estimates of complementarity parameters (Laursen and Mahnke 2001). Whenever organizational practices are complementary, the production function has to be supermodular. This approach is to test complementarity by investigating whether the production function is supermodular. Unlike the correlation approach, this can provide a statistical resolution for complementarity. This approach has been widely used in recent empirical work to test for complementarity among organizational practices in various contexts. For example, Ichniowski et al. (1997) examined the effects of human resource management practices on productivity in a sample of steel finishing lines. Cassiman and Veugelers (2006) analyzed complementarity between two innovation activities: internal research and development and external knowledge acquisition by using an one-tailed t-test on the interaction variable. Lokshin et al. (2004) developed a new testing procedure for complementarity for cases involving multiple (i.e. greater than two) organizational practices that affect output.

A New Framework To Complementarity Testing

We extend the general hypothesis testing of coefficients using classical regression models. Our aim is to present additional statistical results for complementarity that cannot be achieved in the classical framework. The aim of this approach is to develop a set of testable restrictions on the regression model based on the complementarity structure in addition to testing for existence of complementarity.

Testing for Linear Restrictions

A useful approach to testing complementarity hypothesis is to formulate a statistical model that contains the hypothesis as a restriction on its parameters (e.g. Cassiman and Veugelers 2006). There are two ways to impose linear parameter restrictions in model estimation. One way is to substitute the restrictions into the equation to obtain a reparameterized equation. Ordinary Least Squares (OLS) applied to the new equation will yield the restricted equation. The second way is to obtain restricted least squares estimates as the solution to a constrained least squares minimization problem.

To begin with the general form of linear regression model

$$Y = X\beta + \varepsilon \tag{1}$$

And subject to a set of linear restrictions of the form

$$R\beta = q \tag{2}$$

Where R is a matrix with K columns (i.e. number of coefficients β) and J rows (i.e. number of restrictions); and also $J \leq K$. The restriction $R\beta = q$ imposes J restrictions on K otherwise free parameters. Given the least squares estimator b vector, let $m = Rb - q$, the null hypothesis is to test whether m will be exactly 0, i.e. whether the deviation of m from 0 is significant.

We now set up the parameter restrictions based on the complementarity theory. The model has been partitioned into two groups of variables, where the first group X is linearly independent variables and the second group C is the variables to represent the complementarity conditions[6].

$$Y = X\beta + C\gamma + \varepsilon \tag{3}$$

We may use substitution to write this as:

$$R\beta + S\gamma = q \tag{4}$$

If the columns of R are independent, then

$$\gamma = S^{-1}[q - R\beta] \tag{5}$$

The implication is that although β is free to vary, once β is estimated, γ can be estimated using equation (3). Thus, the elements of β are free parameters in the model. This method is to test the complementarity directly by regressing a measure of the dependent variable Y (a measure of performance) on combinations of two binary complementary variables C_1 and C_2.

We proceed to describe the restrictions for testing the different levels of hierarchy of

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[6] If use of practice 1, then $C_1 = 1$. If use of practice 2, then $C_2 = 1$. Then, use none of the two practices = $(1-C_1)(1-C_2)$, use practice 1 only = $C_1(1-C_2)$, use practice 2 only = $(1 - C_1)\, C_2$, use both practices C_1C_2.

complementarity structure. We developed a three-step approach. Formally, given a performance function $\prod(X, C_1, C_2)$ where C_1 and C_2 are hypothesized to be complementary,

$$\prod(X, C_1, C_2; \beta, \gamma) = X\beta + (1-C_1)(1-C_2)\gamma_{00} + C_1(1-C_2)\gamma_{10} + (1-C_1)C_2\gamma_{01} + C_1C_2\gamma_{11} + \varepsilon \qquad (6)$$

Where X is a vector of exogenous (independent) variables hypothesized to have an impact on performance. The two binary variables $C_i \in \{0,1\} \ \ \forall i = 1,2$ indicate the decision (e.g. use or non-use) of a particular practice. The γ_{jk} represents the coefficients of different possible combinations between C_1 and C_2[7]. The test for complementarity between two dummy variables, C_1 and C_2 is:

$$\gamma_{11} - \gamma_{10} \geq \gamma_{01} - \gamma_{00} \qquad (7)$$

This function describes a testable hypothesis where the performance function $\prod()$ is supermodular and C_1 and C_2 are complements, i.e. using both practices has a higher incremental effect on performance than when using any one practice in isolation. In other words, the marginal benefit moving from (0,0) to (1,0) (or to (0,1)) is less than the move from (1,0) (or from (0,1)) to (1,1). Figure 1 shows the three-level structure of the complementarity testing procedure.

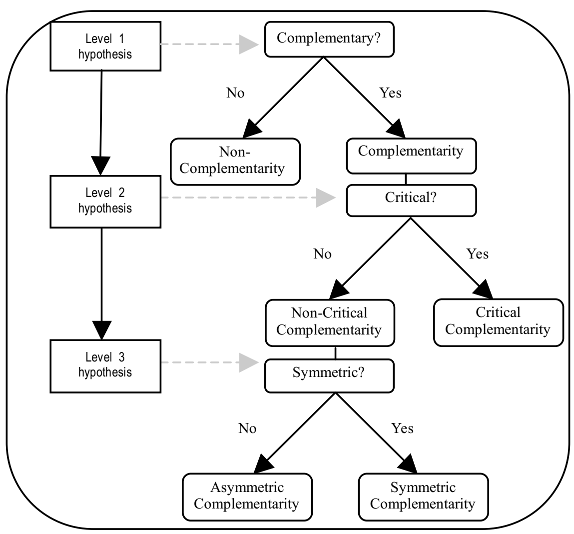

Figure 3: Complementarity Testing Framework.

Three-level testing procedure

Level 1 Test: Complementarity versus non-complementarity

We consider testing the linear restrictions for complementarity hypothesis of the form:

H_0: $\gamma_{11} \geq \gamma_{00}$ and $\gamma_{11} + \gamma_{00} \geq \gamma_{10} + \gamma_{01}$ respectively (8)

The first restriction ensures the performance improvement with both practices being used is significantly higher than neither of the practices being used. The second restriction is implied

[7] In order to provide unbiased estimates, an important assumption for this model is that C_1 and C_2 are uncorrelated with the error term ε.

by the supermodularity condition. Here we consider the first set of two linear restrictions to hold:

$$[0 \quad \ldots \quad 0 \quad -1 \quad 0 \quad 0 \quad 1].\begin{bmatrix} \beta_1 \\ : \\ \beta_k \\ \gamma_{00} \\ \gamma_{10} \\ \gamma_{01} \\ \gamma_{11} \end{bmatrix} \geq [0] \text{ and } [0 \quad \ldots \quad 0 \quad 1 \quad -1 \quad -1 \quad 1].\begin{bmatrix} \beta_1 \\ : \\ \beta_k \\ \gamma_{00} \\ \gamma_{10} \\ \gamma_{01} \\ \gamma_{11} \end{bmatrix} \geq [0] \qquad (9)$$

Level 2 Test: Critical complementarity versus non-critical complementarity
After confirming the existence of complementarity based on the test described in step 1, we consider testing the linear restrictions for critical complementarity hypothesis of the form:

H_0: $\gamma_{10} = \gamma_{00}$ and $\gamma_{01} = \gamma_{00}$ simultaneously
(10)

The two restrictions hypothesize the performance with either one practice being used is not significantly different to the performance with neither of the practice being used. The second set of two linear restrictions to hold simultaneously:

$$\begin{bmatrix} 0 & .. & 0 & 0 & 1 & 0 & -1 \\ 0 & .. & 0 & 0 & 0 & 1 & -1 \end{bmatrix}.\begin{bmatrix} \beta_1 \\ : \\ \beta_k \\ \gamma_{00} \\ \gamma_{10} \\ \gamma_{01} \\ \gamma_{11} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$
(11)

Level 3 Test: Symmetric complementarity versus asymmetric complementarity

After confirming the non-critical complementarity based on the test described in step 2, we consider testing for symmetric complementarity hypothesis of the form:

H_0: $\gamma_{10} = \gamma_{00}$ or $\gamma_{01} = \gamma_{00}$ independently
(12)

Based on the results from level 2, the performance with at least one practice being used is significantly different from the performance with neither of the practices being used.

$$
\begin{bmatrix} 0 & .. & 0 & 0 & 1 & 0 & -1 \end{bmatrix} \cdot \begin{bmatrix} \beta_1 \\ \vdots \\ \beta_k \\ \gamma_{00} \\ \gamma_{10} \\ \gamma_{01} \\ \gamma_{11} \end{bmatrix} = 0 \quad \text{(13a)} \quad \text{or} \quad \begin{bmatrix} 0 & .. & 0 & 0 & 0 & 1 & -1 \end{bmatrix} \cdot \begin{bmatrix} \beta_1 \\ \vdots \\ \beta_k \\ \gamma_{00} \\ \gamma_{10} \\ \gamma_{01} \\ \gamma_{11} \end{bmatrix} = 0 \quad \text{(13b)}
$$

There are two possible complementarity structures for non-critical complementarity. First, if both hypotheses (13a and 13b) are rejected, it implies symmetric complementarity. Second, if only one of the 2 hypotheses (either 13a or 13b) is rejected, it implies asymmetric complementarity. The testing procedures are shown in Figure 2.

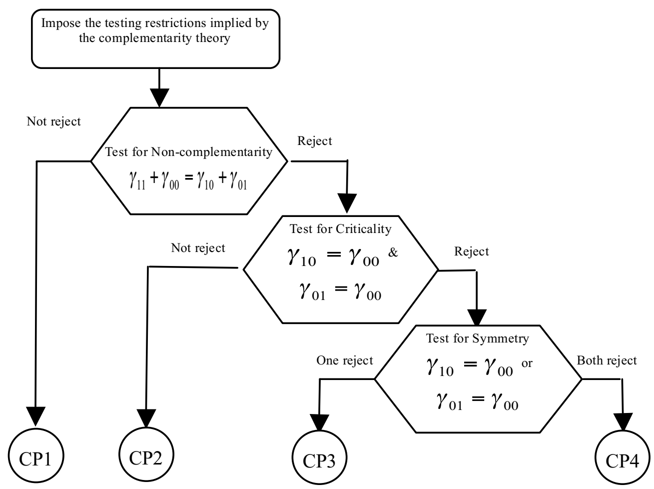

Figure 2: Testing Procedures

CP1: Non-complementarity describes a condition in which implementing C_1 does not have any effect to the returns to C_2 or vice versa (i.e. supermodularity condition does not hold).

CP2: Critical complementarity (see Figure 3) describes a condition in which there is incremental performance by implementing C_1 and C_2 simultaneously. Positive performance impact can only be achieved by the implementation of both input strategies.

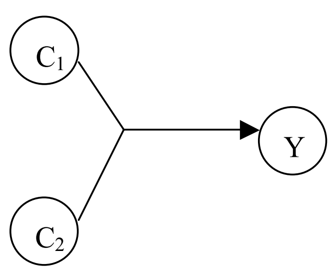

Figure 3: Critical complementarity

CP3: Non-critical asymmetric complementarity (see Figure 4) describes a condition that only one strategy has positive incremental impact on performance when it is implemented independently, where symmetric complementarity describes a condition in which both input variables behave in a similar manner in effecting the performance outcome.

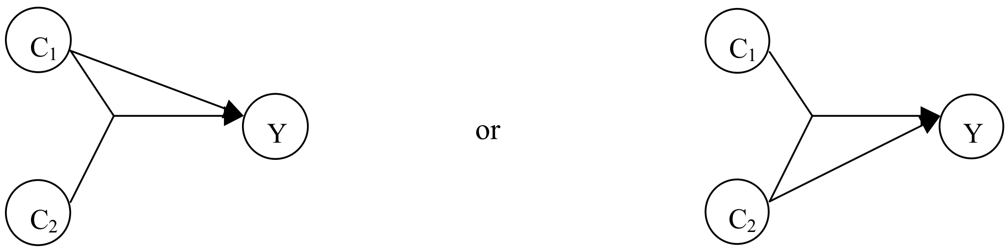

Figure 4: Non-critical asymmetric complementarity

Because only one of these two conditions holds, it implies that only the one practice with such condition can impact performance independently, and the other practice is playing a supportive role to further enhance the impact of C_1 on performance *Y*. The top figure in Figure 4 illustrates the asymmetric complementarity condition, when C_1 has direct impact on *Y*. C_2 is the moderator to enhance the performance impact of C_1.

CP4: Non-critical symmetric complementarity (see Figure 5) describes a condition in which there is significant performance enhancement by implementing C_1 and C_2 simultaneously. However, positive performance impact can be achieved by the implementation of either practice.

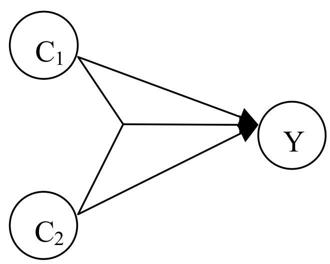

Figure 5: Non-critical symmetric complementarity

Empirical Application

In order to illustrate the method, this study examined the relationships among KM strategies and their impacts on knowledge creation processes. KM strategies can be primarily categorized by using two key dimensions, i.e., (i) KM focus and (ii) KM source. Along with KM focus dimension, KM strategies can be classified into explicit- and tacit-oriented. Explicit-oriented strategy put more emphasis on codifying and reusing knowledge in order to increase organizational efficiencies through advanced information technologies and thus decrease the complexity of using knowledge (Hansen et al. 1999). The emphasis of tacit-oriented strategy is on the acquiring and sharing tacit knowledge through direct person-to-person contact and through informal social networks (Zack 1999b).

The second dimension to orient to a KM strategy is to describe the firm's primary source knowledge (Zack 1999a). On the KM source dimension, KM strategies can be categorized as internal- and external-orientation (Bierly and Chakrabarti 1996). External-oriented strategy focuses on bring knowledge from outside the firm through either acquisition or imitation and then transferring the knowledge throughout the organization. Internal-oriented strategy emphasizes creating and sharing knowledge within the boundary of the firm. Knowledge within the firm tends to unique and tacitly, resulting in strategic value.

Our main purpose here is to illustrate the validity and usability of the proposed complementarity testing procedure. Thus, details on data such as gathering method, analysis procedure, and full results are not presented.[8]

Three empirical applications are presented. In example 1, we test the complementary relationship between explicit-oriented and tacit-oriented strategies in terms of KM focus. In the second example, the complementary relationship between internal-oriented and external-oriented strategies in terms of KM source is evaluated. The third example tests the complementary relationship between tacit-internal and explicit-external strategies by considering KM focus and KM source together. The data for this study was gathered from 115 listed major companies in Korea. Annual Corporation Reports by Maeil Business Newspaper (2000) served as the target population. The performance variable is the knowledge creation processes which were proposed by Nonaka (1994).

In example one, we consider the impact of tacit-oriented and explicit-oriented strategies that can be pursued simultaneously or exclusively. The results of the test are reported in Table 1a. In the first step, the $\gamma_{11} + \gamma_{00} \geq \gamma_{10} + \gamma_{01}$ model is estimated in order to test complementary relationship between tacit-oriented and explicit-oriented strategies. The test result for complementarity is not acceptable (p value = 0.31864). This result suggests that organizations do not need to implement tacit-oriented and explicit-oriented strategy simultaneously for achieving high level of knowledge creation processes. The test should be terminated because it does not hold complementarity condition. In the second example, this study examines the impact of four KM strategies (high internal-& high external-oriented; high internal-oriented; high external-oriented; low internal-& low external-oriented) on knowledge creation processes based on KM source. Table 1b shows the results.

Table 1. Complementarity of KM focus and Complementary of KM source

KM strategies	Knowledge creation processes	Multiple comparison (by Duncan Method)
HT& HE (γ_{11})	4.4044 (0.11)	$\gamma_{11} > \gamma_{10} = \gamma_{01} > \gamma_{00}$
HE & T (γ_{10})	4.0692 (0.11)	
HT & LE (γ_{01})	3.9270 (0.08)	
LT & LE (γ_{00})	3.3830 (0.12)	
Test for complementarity $\gamma_{11} + \gamma_{00} \geq \gamma_{10} + \gamma_{01}$		F (1, 111) = 1.00 p-value = 0.31864
Result	Non-complementarity	

Note: HT: High tacit-oriented; HE: High explicit-oriented; LT: Low tacit-oriented; LE: Low explicit-oriented

(a) Complementarity of KM focus

KM strategies	Knowledge creation processes	Multiple comparison (by Duncan Method)
HI & HEx (γ_{11})	4.3059 (0.18)	$\gamma_{11} > \gamma_{10} > \gamma_{01} > \gamma_{00}$
HI & LEx (γ_{10})	3.8240 (0.11)	
HEx & LI (γ_{01})	3.5667 (0.16)	
LI & LEx (γ_{00})	3.3083 (0.15)	
Test for complementarity $\gamma_{11} + \gamma_{00} \geq \gamma_{10} + \gamma_{01}$		F (1, 111) = 0.52 p-value = 0.47184
Result	Non-complementarity	

Note: HI: High internal-oriented; HEx: High external-oriented; LI: Low internal-oriented; LEx: Low external-oriented

(b) Complementarity of KM source

The direct test for complementarity ($\gamma_{11} + \gamma_{00} \geq \gamma_{10} + \gamma_{01}$) is again rejected. This implies that adopting internal-oriented KM strategy is less efficient in case it is accompanied by external-

[8] Further details on the data and measure are available in Choi et al. (2007) and Lee and Choi (2003). The full results are available from the authors upon request.

oriented strategy. Since the model displays no evidence of complementarity, no further tests are required. The impact of complementary relationship between tacit-internal and explicit-external strategies on knowledge creation processes is examined by considering KM focus and KM source in the third example. The results are reported in Table 2.

Table 2. Complementary between KM focus and KM source

KM strategies	Knowledge creation processes	Multiple comparison (by Duncan Method)
HTI & HEE (γ_{11})	5.0280 (0.13)	$\gamma_{11} > \gamma_{10} > \gamma_{01} > \gamma_{00}$
HTI (γ_{10})	4.2070 (0.06)	
HEE (γ_{01})	3.8103 (0.08)	
LTI & LEE (γ_{00})	3.3088 (0.08)	
Test for complementarity ($\gamma_{11} + \gamma_{00} \geq \gamma_{10} + \gamma_{01}$)		F (1, 111) = 3.34* (p-value = 0.07043)
Test for criticality ($\gamma_{10} \geq \gamma_{00}$ and $\gamma_{01} \geq \gamma_{00}$)		F (2, 111) = 41.27*** (p-value= 0.00000)
Test for symmetry ($\gamma_{10} \geq \gamma_{00}$ or $\gamma_{01} \geq \gamma_{00}$)		F (1, 111) = 81.62*** (p-value= 0.00000) or F (1, 111) = 22.63*** (p-value= 0.00001)
Result	Non-critical symmetric complementarity	

Note: HTI: High tacit-internal; HEE: High explicit-external; LTI: Low tacit-internal; LEE: Low explicit-external (***: p < 0.01, **: p < 0.05, *: p < 0.1)

In the first step, the $\gamma_{11} + \gamma_{00} \geq \gamma_{10} + \gamma_{01}$ model is estimated in order to test complementary relationship between tacit-internal and explicit-external strategies. The test for complementarity is accepted at a 0.10 level of significance (p value = 0.07043). This result suggests that organizations should implement tacit-internal and explicit-external strategies simultaneously for achieving high level of knowledge creation processes. In the second step, $\gamma_{10} \geq \gamma_{00}$ and $\gamma_{01} \geq \gamma_{00}$ model is estimated simultaneously for criticality test. The result shows non-critical complementary relationship between tacit-oriented and explicit-oriented strategies at a 1% level of significance (p value = 0.00000). In the final step, we test $\gamma_{10} \geq \gamma_{00}$ or $\gamma_{01} \geq \gamma_{00}$ model independently in order to find symmetric characteristics of the relationship. The test for symmetry is accepted at a 0.01 level of significance (p-value = 0.00000 and 0.00001). The results of step 2 and 3 imply that it is not necessary to employ both strategies (i.e., tacit-internal and explicit-external) together because adopting any one of them can also result in improved level of knowledge creation processes.

It is well understood that organizations need to consider the deeper issues in the form of complementarities in order to maximize the returns. It is also important for organizations to effectively manage such synergistic relationship between business practices. The challenge for organizations is not only to identify and to pay attention to the complementary practices and to develop strategies to manage and transform those practices into strategic competitiveness in a sustainable way. Understanding the complementarity structure among these practices is critical. Additional performance comes from the artful consideration of the interrelated and mutually dependent (i.e. complementary) factors. This study develops a test for complementarity using a supermodular function approach in which organizational practices affect performance. Furthermore, this study has revealed a number of distinct complementary relationship structures among organizational practices based on the theory of complementarities.

Conclusion

The empirical framework developed in this paper has provided statistical examination of complex relationships between organizational practices. In particular, the three-level testing procedure applies a linear restrictions test which enables the classification of complementary structures. The analytical examples are demonstrated for KM strategies and knowledge creation processes. With empirical studies of complementarity gaining prominence in a number of related disciplines such as economics and organization studies, the procedure developed in this study can be of considerable value to both academics and managers. However, the proposed procedure is not available to test for complementarity with more than two organizational practices. Future research to extend the method in order to examine more than two potentially complementary practices is needed.

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