An Empirical Examination of the R&D Boundaries of the Firm —A Problem-solving Perspective

Shaopeng Huang[ǂ], Darryl Holden

University of Strathclyde

Abstract

We consider, both theoretically and empirically, how different organization modes are aligned to govern the efficient solving of technological problems. The data set is a sample from the Chinese consumer electronics industry. Following mainly the problem solving perspective (PSP) within the knowledge based view (KBV), we develop and test several PSP and KBV hypotheses, in conjunction with competing transaction cost economics (TCE) alternatives, in an examination of the determinants of the R&D organization mode. The results show that a firm's existing knowledge base is the single most important explanatory variable. Problem complexity and decomposability are also found to be important, consistent with the theoretical predictions of the PSP, but it is suggested that these two dimensions need to be treated as separate variables. TCE hypotheses also receive some support, but the estimation results seem more supportive of the PSP and the KBV than the TCE.

Key Words: Problem-solving perspective, knowledge-based view, firm boundaries

[ǂ] Corresponding author: Shaopeng Huang, Department of Economics, University of Strathclyde, 130 Rottenrow G4 0GE, Glasgow, UK, E-mail: Shaopeng.huang@gmail.com

1. Introduction

The emergence of the problem-solving perspective (PSP) (Macher, 2006; Nickerson *et al.*, 2004) within the knowledge-based view (KBV) is a major development in the theory of the firm. It seeks to combine transaction cost economics (TCE) (Williamson, 1985, 1996), complexity theory (Simon, 1962; Kauffman, 1995) and the KBV of the firm (Conner, 1991; Conner *et al.*, 1996; Foss, 1996; Kogut *et al.*, 1992) to explain how different organization modes are aligned to govern the efficient creation of valuable knowledge. In this perspective the firm is a knowledge-bearing problem solving entity, with the key tasks of management being the identification of valuable problems and the organization of solution searches. The firm, by organizing problem finding and problem solving efficiently, creates value.

Although adopting a different unit of analysis than TCE, the PSP applies similarly the logic of 'discriminating alignment' (Williamson, 1991) in evaluating the relative costs of organizing problem solving under alternative organization modes. Based on previous work, a few dimensions are identified as being crucial to understanding the impediments to problem solving. Furthermore it is contended that as far as the costs and competencies of implementing solution searches for different types of problem are concerned, the few generic organization modes differ systematically with respect to incentive intensity, communication channels, dispute resolution regimes, etc. Finally, the PSP works out the match between problem/knowledge attributes and the few generic organization modes in an economizing manner that realizes superior search performance.

As an emerging perspective, empirical examinations of the PSP are underdeveloped. Although the organizational implications of many relevant variables have been explored in related literature, few empirical studies (Macher, 2006; Macher *et al.*, 2012) are directly designed to examine the PSP. This paper seeks to address this shortcoming by developing and testing some PSP/KBV hypotheses in conjunction with other competing TCE alternatives, in an examination of the determinants of the firm's R&D organization choice. The data set used relates to the Chinese consumer electronics industry. Following the PSP, we use measures of problem complexity (problem structure, intensity of knowledge-set interactions, and decomposability), and measures of knowledge tacitness and social distribution as predictors. In particular, we argue that *intensity of knowledge set interactions* and *decomposability* are analytically distinguishable. We therefore treat them as two separate variables and find that they have rather different effects on the organization choice. Moreover, with reference to other closely related literature, we contend that a firm's existing knowledge base has profound impacts on the organization of its problem solving activities, but that this dimension has been relatively ignored in the existing PSP literature. We introduce an appropriate measure into the analysis and find it to be a significant predictor. Finally, to compare the relative explanatory power of competing theories, a few relevant TCE variables are also included.

The paper proceeds as follows. Section 2 reviews the PSP literature, on which basis hypotheses are developed. Section 3 sets the empirical context, highlighting the industrial background, describing the data and the variables. Section 4 presents and discusses the estimation results. The final section makes concluding remarks.

2. Literature Review and Hypotheses Development

In the PSP, the 'problem' is the basic unit of analysis and the profitable discovery of a high-value solution for a given problem is the central rationale for choosing the organization mode. It is assumed that new knowledge is generated by combining existing knowledge, and that a solution to a problem represents a unique combination of existing knowledge. For any given problem, the set of all possible combinations of relevant knowledge is presented as a solution landscape, the topography of which defines the value of each solution. Accordingly, problem solving can be seen as a process of searching over the solution landscape for high value solutions (Nickerson *et al.*, 2004).

Building on Simon's work on problem solving (1962, 1973), and Kogut and Zander's contributions to the KBV of the firm (1988; 1992), certain problem attributes (complexity, decomposability, and problem structure) and knowledge characteristics (tacitness and social distribution) are identified as critical dimensions for understanding the coordination and incentive challenges to problem solving. Moreover, proponents of the PSP endorse the KBV argument that hierarchies enjoy advantages over other organization modes, either because they facilitate knowledge exchange via the cultivation of organization-specific communication codes, shared language and routines (Grant, 1996; Kogut *et al.*, 1992; Nelson *et al.*, 1982) or because they economize on knowledge transfer by exercising authority and direction (Conner *et al.*, 1996; Demsetz, 1988). They further propose the 'discriminating alignment' that defines the match between problem attributes, knowledge characteristics and organization modes. They argue (Leiblein *et al.*, 2009; Macher, 2006; Nickerson *et al.*, 2004) that given the above-mentioned advantages, together with the control mechanisms and low-powered incentives characteristic of internal organization (Williamson, 1991), hierarchies are better able to implement heuristic search through information dissemination, consensus building, and authority direction as compared to markets. Therefore, hierarchies realize solution search performance advantages for ill-structured, complex or non-decomposable problems which typically involve tacit and socially distributed knowledge. By contrast, markets enjoy certain advantages arising from more specialized expertise (Hayek, 1945), high-powered incentives, decentralized decision making (Williamson, 1991) and more direct competitive pressures (D'Aveni *et al.*, 1994), so that markets improve the speed/quality of problem solving via directional search when technological development involves well-structured, simple or decomposable problems.

Somewhat paradoxically, in the PSP literature, the organizational implications of a firm's existing knowledge base have been relatively ignored, although recent literature (Macher *et al.*, 2012) has begun to address this issue. By contrast, in the KBV literature on which the PSP is grounded, it is firmly held that a firm's existing knowledge base has profound organizational consequences, and this view has been applied to the organization of a firm's R&D activities (e.g., Zhang *et al.*, 2007). Given this, we suggest that this dimension is of particular relevance to the organization of problem solving and that its role should be highlighted and restored.

2.1 Complexity (*Intensity of Knowledge Set Interactions*) *and Decomposability*

These two dimensions were introduced to the PSP literature by Nickerson and Zenger (2004), with their origins traced back to Simon (1962), who argues that complexity obtains when a large number of parts making up a system interact in a non-simple way. As a system, complexity frequently takes the form of a "hierarchy" consisting of interrelated subsystems which, in turn, are hierarchical in nature until some elementary subsystem being reached at the lowest level. In a hierarchical system, the interactions *amongst* and *within* subsystems are distinguished, and the distinction between decomposable, non-decomposable and nearly decomposable systems is made accordingly. In a decomposable (non-decomposable) system, the interactions amongst subsystems are negligible (essential); whilst in a nearly decomposable system, the interactions amongst the subsystems are *weak*, *but not negligible*.

On the basis of this and other subsequent contributions, the complexity of problems is divided into three broad categories (Nickerson and Zenger, 2004), depending on the extent to which relevant knowledge sets interact to produce a valuable solution (Leiblein *et al.*, 2009).

For (fully-) *decomposable and low-interaction problems*, interdependencies amongst relevant knowledge sets are negligible and decomposition into sub-problems is easy. Solving such problems requires little coordination and knowledge sharing. Impediments to knowledge sharing are less relevant. *Local trial-and-error* (directional) search through experiential learning and feedback provides certain advantages. Decomposability also implies that the solutions to each sub-problems are additive (Leiblein *et al.*, 2009). Sub-problems can be solved independently and simultaneously, with the optimal solutions to sub-problems being readily aggregated to give a globally optimal solution for the original problem.

At the other extreme are *non-decomposable and high-interaction problems*, for which there exist intensive and extensive interactions amongst knowledge sets, with there being no practical pattern of decomposability. To solve such problems, *cognitive*/*heuristic search* is prescribed, calling for problem solvers to collectively develop cognitive maps to navigate the search (Gavetti *et al.*, 2000; Simon, 1988) which in turn necessitates the sharing/exchange of knowledge amongst multiple actors. As specialists from different fields are cognitively constrained in the speed at which they can learn, the task of coordinating and aggregating specialists' knowledge is demanding (Hsieh et al., 2007). Moreover, given self-interestedness, incentive impediments such as *knowledge appropriation hazards* and strategic *knowledge accumulation hazards* tend to complicate the organization of solution discovery (Nickerson *et al.*, 2004).

Between the above extremes are *nearly-decomposable and moderate-interaction problems*, for which the interactions amongst relevant knowledge sets are moderate. Sub-problems associated with distinctive knowledge sets can be identified, but where non-trivial interdependencies amongst the sub-problems remain. Near-decomposability also means that knowledge-set interactions *within* sub-problems are greater than *amongst* sub-problems, so that the solution search requires some knowledge sharing and coordination. Accordingly, the aforementioned coordination and incentive challenges still apply, albeit on a reduced scale.

With reference to the *NK* system (Kauffman, 1993), the complexity of a given problem can be defined more analytically by *N* (the number of relevant knowledge sets) and *K* (the magnitude of interdependence) (Nickerson *et al.*, 2004). Simple problems involve a small number of relevant knowledge sets interacting in more predictable ways, mapping into smooth solution landscapes. Whilst complex problems entail a larger number of relevant knowledge sets, amongst which there are pervasive interactions and extensive connectivity, some of which do not allow direct observation, with the implied solution landscapes tending to be more rugged. Intuitively, the likelihood of conflicting constraints across choices also increases with *N* and *K* (Kauffman, 1993), the solving of complex problems thus requires the balancing of multiple design choices, adding to the difficulty of finding the global optima (Jonassen, 2004).

Notwithstanding the above, it is noted that the existing PSP literature does not particularly differentiate between knowledge set interactions and problem decomposability. Theoretically, they are considered as two concomitant properties along the same dimension (e.g., Nickerson & Zenger, 2004) and empirically they are treated as a single variable, captured by the same measure (Macher, 2006; Macher *et al.*, 2012). However, knowledge set interactions and problem decomposability are analytically distinguishable and do not always move in the same direction. By definition (Nickerson *et al.*, 2004; Simon, 1962), knowledge set interactions capture the ***intensity*** of interactions whereas decomposability depends on the ***pattern*** of such interactions. In particular decomposability indicates that such interactions are not diffuse but tend cluster tightly into nearly isolated subsets of interactions (Ethiraj *et al.*, 2004).

To illustrate the difference, consider the three *NK* systems in Figure 1. In each case, *N*=6, *K*=1 and there are 12 interactions amongst the elements. In terms of intensity of knowledge set interactions, the three systems are equally complex but they exhibit different patterns of decomposability.

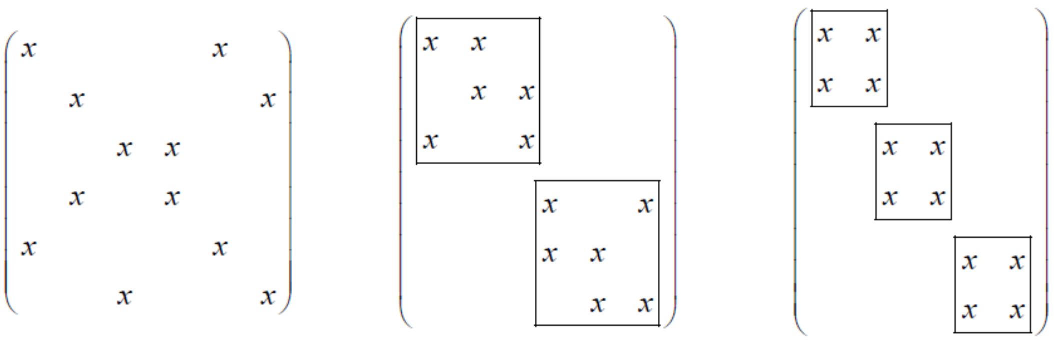


Figure 1: The Interaction Matrices of Three NK Systems (*N*=6, *K*=1) with Different Patterns of Decomposability

The *x* value in the matrix stands for the interaction between the corresponding components. For example, the *x* value on row *i* and column *j* represents for the extent to which the function of element *i* is influenced by a change of element *j*. An interaction is always present on the diagonal since the functioning of a component depends on its own design.

System 1 displays random interactions with no obvious pattern of decomposability. By contrast, system 2 and system 3 can be decomposed into two and three subsystems respectively. In terms of non-decomposability, system 1 is more complex than system 2 which is, in turn, more complex than system 3.

Given the above analysis, knowledge set interactions and problem decomposability are treated as two separate variables in this study and we try to differentiate their respective effects on the organization choice in the empirical analysis.

2.2 Definiteness of Problem Structure

In the complexity theory the definiteness of problem structure has long been recognized as a distinct dimension of problem complexity (Simon, 1973). According to Simon, virtually all problems are initially ill-structured. They become well-structured problem as problem solvers become increasingly prepared for, and more familiar with, them. Such a process of formalization renders problems solvable. Well-structured problems are the outcomes of problem-defining processes and the accumulation of problem solving techniques.

In the PSP literature, the dimension of problem structure was introduced by Macher (2006). Building mainly on Simon's work, and with reference to the *NK* system, Macher argues that problems can be characterized along a continuum of problem definiteness, ranging from ill-structured to well-structured. The extent to which a problem is well-structured depends on the characteristics of the problem domain on the one hand, and on the availability and clarity of the problem solving mechanisms on the other. Ill-structured problems have poorly defined initial states (ambiguous *N* and *K*) (Jonassen, 2004) and unexpected/unknown knowledge set interactions (Fernandes *et al.*, 1999), so that appropriate approaches to problem solving are unclear. By contrast, well-structured problems are those with well-defined initial states (unambiguous *N* and *K*) and well understood knowledge set interactions. Accordingly, the appropriate approaches to problem solving are explicit and well-accepted.

As these differences also have implications for problem decomposability (Ethiraj *et al.*, 2004; Levinthal, 1997), a connection between problem structure and decomposability can be made (Macher, 2006). Ill-structured problems cannot be decomposed because the knowledge set interactions are often unexpected/unknown, making the solution searches difficult. By contrast, the knowledge set interactions for well-structured problems are better understood, implying solution searches are more transparent.

Although the definiteness of problem structure does not affect the topography of the solution landscape (Leiblein *et al.*, 2009), it does have implications for the relative performance of different solution search strategies. For ill-structured problems, heuristic search realizes performance advantages via *ex ante* cognitive evaluations of the probable consequences of particular search decisions, as opposed to *ex post* reliance on feedback from previous trials (Simon, 1991). Whilst for well-structured problems, directional search guided by feedback or experiential learning is more efficient in achieving high-value solutions compared to heuristic search (Gavetti *et al.*, 2000; Simon, 1973).

In summary, in the above two subsections it is argued that the nature and magnitude of coordination and incentive challenges to problem solving vary systematically across problem types, with which different search methods can be matched in a way that realizes superior search performance. Furthermore, combining insights from both the TCE and the KBV, it is argued that the costs and competencies of implementing solution searches for different types of problem (via different search methods) differ across the few generic organizational modes. It follows naturally that high value solutions to a particular type of problem can be most efficiently organized by some specific organization mode. In the PSP literature, the discriminating alignment (Macher, 2006; Nickerson *et al.*, 2004) dictates that markets are most suitable when problems are simple, decomposable and well-structured. Of the two types of hierarchy differentiated by Nickerson and Zenger (2004), the consensus-based hierarchy entails high organization costs and should only be adopted when the benefits from building consensus and developing collective heuristics are high, this being the case when the problem is highly complex, non-decomposable and ill-structured. The authority-based hierarchy is superior to markets in supporting heuristic search, but inferior in supporting directional search, so that it is most suited for problems that are averagely complex, nearly-decomposable and moderately ill-structured.

2.3 A Firm's Existing Knowledge Base

Above, it is noted that the extent to which a problem is well-structured depends on how well the problem solvers are prepared for it. It should be emphasized that the idea can in fact be operationalized on two different levels, which, in our view, have distinct organizational consequences. On a collective level, whether a problem is well-structured depends on how much human beings as a whole know about the problem, and the extent to which they have developed corresponding techniques for solving it. This, as we understand it, is what is discussed in the previous section. On an individual level, given the 'state of the art' for solving a specific problem, whether and how well/fast a problem solver is able to find a solution also depends on how well this problem solver is equipped with relevant knowledge. In this sense, problem structure is solver-dependent, and consequently related to a firm's existing knowledge base. It follows, more generally, that a given problem can pose radically different challenges for different problem solvers with different knowledge backgrounds, thus leading to different organization choices and performances. Similar points have been made by Macher and Boerner (2012) who contended that firms with more technological knowledge in relevant fields can improve performance not only via experiential learning by doing, which tends to favour the choice of internal development, but also through better supplier relationship management, which instead tends to favour the choice of markets, so that a firm's technological knowledge base is "likely to have organization and performance implications that depend in part on the structure of technological development" (Macher *et al.*, 2012: p. 3). In other words, a firm's existing knowledge base affects the organization and the performance of its problem solving activities, both through its ***independent effect***[1] and through its ***interaction effect*** with the structure of the problem.

With the exception of Macher and Boerner (2012), the possible linkage between a firm's existing knowledge base and its organization choice is little discussed in the PSP literature. By contrast in the KBV, the organizational learning, and the innovation literatures, a firm's existing knowledge base has been found, both theoretically and empirically, to have profound organizational consequences. Its implications for the organization of technological problem solving have also been explored (e.g. Zhang et al., 2007).

As also noted by Macher and Boerner (2012), in the KBV literature the firm is conceptualized as an routine-based, history-dependent knowledge bearing social entity that adapts experimentally and incrementally to its past experiences (Penrose, 1955). Its existing knowledge base provides the firm with more in place information filters (Arrow, 1974), absorptive capacity (Cohen *et al.*, 1990), and routines (Nelson *et al.*, 1982) that facilitate the integration of knowledge (Kogut *et al.*, 1992) and improve problem solving efficiency in specific technological areas (Nelson *et al.*, 1982). Accordingly more experienced/knowledgeable firms achieve superior performance in technological development, irrespective of the mode of organization (Macher, 2006). More substantially, a more experienced/knowledgeable firm enjoys experiential learning-by-doing and uncertainty reduction performance advantages, so that it tends to in-source its technological development (Argote, 1999). More generally, in this literature it is firmly held that firms tend to internalize activities in which they have superior capabilities, and outsource those in which they have inferior capabilities (Argyres, 1996). Recent work (Coombs *et al.*, 2000; Grant *et al.*, 2004) also reveal that, in many cases, firms participate in various forms of alliance mainly to access external complementary knowledge/capabilities. A link between alliance participation and a firm's knowledge base can thus be established.

Applying the above insights in the context of technological problem solving, it can be argued that a firm with a higher level of knowledge in relevant fields is more likely to organize problem solving in-house rather than through markets, *ceteris paribus*.

[1] However the authors appear rather ambiguous regarding the organizational implications of a firm's existing knowledge base as they stated that more experienced firms perform better both "in developing knowledge ***within*** and integrating knowledge ***across*** organizational boundaries" (Macher & Boerner, 2012: p. 16, emphasis added), so that they have greater organizational ***flexibility*** in technological development. They appear agnostic as to whether a firm's existing knowledge base has an independent impact on its organization choices, and they tend to believe that such an effect is neutral with respect to make-or-buy decisions.

Similarly, when a firm is trying to solve a complex problem, for which it has considerable knowledge but is nevertheless lacking in some critical knowledge direction, it would, depending on the attributes of the problem, leverage various forms of collaborative arrangements to access external complementary knowledge.

2.4 Knowledge Tacitness and Social Distribution

In the KBV of the firm tacit, contextually dependent, and socially distributed knowledge are of central explanatory importance. This theme is mainly developed by Kougut and Zander but can be traced back to Polanyi (1962, 1966).

In a series of papers (1988; 1992, 1995, 1996), Kogut and Zander explore the boundary implications of tacit and socially distributed knowledge, with further development due to Langlois and others. (Hippel, 1994; Langlois, 1992; Langlois *et al.*, 1999). As indicated by Langlois and Foss (1999), at the heart of these stories is the argument that productive knowledge is often hard to articulate and not possessed by any single mind. Instead, it is distributed among a group of interacting agents, emerging from the aggregation of the tacit knowledge elements they possess. Moreover, such knowledge is often contextually sensitive in that it can only be mobilized in the firm-specific context of carrying out a multi-person productive task. Therefore, when such knowledge is to be transferred across firm interfaces, a firm may have difficulty understanding the knowledge and capabilities held by another firm, and both firms separately and jointly may "know more than their contracts can tell" (Kogut and Zander 1992), thus adding to the contractual complications. In this context, the costs of negotiating and making contracts with potential partners, of teaching and educating the contractual counterparts, …, become very real factors that shape the firm boundary (Langlois, 1992), whereas such costs are rather independent of opportunism (Kogut, 1988). Relative *transformation costs*[2] of different firms, rather than *transaction costs*, seem to be the primary issue (Kogut *et al.*, 1995). Firms tend to internalize the utilization of tacit and socially distributed knowledge as internalization economizes on the costs associated with its transmission (Kogut & Zander, 1992). This is possible not because firms can provide better incentive alignments, but because they can supply a set of "higher-order organizing principles of how to coordinate groups and transfer knowledge"[3] (Kogut & Zander, 1992) that markets cannot offer, because coordination, communication, and learning "are

[2] The transformation (production) costs/transaction costs dichotomy was made by Wallis and North (1986).
[3] According to the authors, these "higher-order organizing principles" include, among others, "shared coding schemes", "values", and "a shared language". They act as "mechanisms by which to codify technologies into a language accessible to a wider circle of individuals"; so that "varieties of functional expertise can be communicated and combined" (Kogut & Zander 1992: pp. 389-90) within the social community of the firm.

situated not only physically in locality, but also mentally in an identity" (Kogut & Zander, 1996).

Apart from the make-or-buy decision, similar reasoning has been applied to the choice of alliance governance (Kogut, 1988). In this literature it is generally argued that equity-based alliances are more effective than contract-based alliances for the transferring of tacit and socially embedded knowledge between partner firms, as equity-based alliances (in particular, joint ventures) tend to promote frequent and direct interactions, increase mutual understanding, enhance knowledge transparency, and offer better opportunities for interactive learning. The arguments have subsequently been developed by Heiman and Nickerson (2002, 2004) who incorporate the logics of the PSP and the TCE. They argue that inter-firm collaboration can be understood as a problem solving process involving the combining of the distinct knowledge sets of the participants, those often being tacit and socially distributed. Given the cognitive limitations of human beings, such knowledge characteristics can interact with problem complexity to pose significant challenges for the sharing/transferring of knowledge in the process of joint solution search. To overcome these challenges, various knowledge management practices (e.g., high-bandwidth communication channels and common communication codes) are often adopted. However, given opportunism, the adoption of these measures gives rise to higher knowledge appropriation hazards via increased knowledge transparency. Efficient inter-firm collaboration governance should therefore address the problems of knowledge transfer and knowledge expropriation jointly. They suggest that an equity-based alliance can deal with both problems more effectively than a contract-based alliance. On the one hand, with the aid of the hierarchical structure and a whole package of coordination and administrative apparatuses, an equity-based alliance is better able to accommodate the afore-mentioned knowledge management practices, making it a superior vehicle for transferring/sharing complex knowledge. On the other hand, equity-based governance also provides better safeguards against misappropriation of knowledge as shared ownership tends to alleviate opportunistic incentives, increase monitoring, and enhance managerial controls.

2.5 Hypotheses

Based on the above review we have the hypotheses presented in Table 1, with reference to which we note the following.

First, in the view of standard TCE (Williamson, 1991), collaborative arrangements (alliances) are generally regarded as 'hybrid' modes of organization lying somewhere between market and hierarchy along a hypothetical continuum. This implies that if a higher value of an explanatory variable favours the choice of in-house over outsourcing, it also favours the choice of in-house over alliance and the choice of alliance over outsourcing. In the PSP literature such a view has been adopted by Leiblein and Macher (2009) who argue that alliances (in particular, joint ventures) are better than markets in solving ill-structured or complex problems, but perhaps not suitable for the most ill-structured or complex problems in comparison to hierarchies. In this study, the *default* hypotheses are developed in this spirit.

Secondly, in the TCE literature, it is also generally held that equity-based alliances are more hierarchical than contract-based alliances along the market-hierarchy continuum (Oxley, 1997). Hypotheses regarding the choice of any specific pair of organization modes could thus be inferred.

Thirdly, the view that alliances are "hybrid" modes of organization has been questioned (e.g., Kay, 1997). As indicated by Kay (1997), a joint venture, presumably the most important 'hybrid' mode, is typically plagued by the problem of being the servant of several masters, with the implied contractual, control and appropriability problems all tending to exacerbate transaction costs relative to a pure hierarchy. In other words, a joint venture carries the burden of both hierarchical and market arrangements, tending to make its transaction costs greater than those of the corresponding pure forms. Much of the managerial literature also suggests that a joint venture is often viewed by managers as the most expensive mode of organization, a last resort dominated by other modes (Brechbuhl, 2006). In this view it is problematic to treat alliances (in particular, joint ventures) as 'hybrid'. Rather, they should be viewed as an independent category of organization modes. Although such expansive modes are generally avoided, alliances, however, do offer some unique benefits—in particular, access to external to external complementary knowledge in the face of solving a non-decomposable, complex problem that is beyond the firm's existing capabilities/knowledge base. It can therefore be argued that the likelihood of knowledge/capabilities bottlenecks increases with problem complexity, and such bottlenecks might be expected to lead the firm to referring to external sources for complementary knowledge, most possibly by forming alliances with other firms (Coombs *et al.*, 2000). In the context of choosing between in-house and alliance, it seems reasonable to argue that the more complex the problem the less likely it can be solved internally, for lack of complete knowledge, and therefore the more likely the problem solving will be organized by alliance. In Table 1, some *alternative hypotheses* are developed in this spirit. In our view, these alterative hypotheses are consistent with the logics of the PSP and the KBV, although they are at odds with the 'hybrid' view of alliances.

Finally, given space constraints and the focus of the article, we do not review the relevant TCE literature. For the few TCE variables included in this study we adopt rather standard TCE hypotheses.

Table 1: Summary of Hypotheses

Theoretical Perspective	Variable (taking value from 1 to 5)	*Predicted Sign of Estimated Coefficients in the Multinomial Logit Model* [ǂ]		
		Equity-based Alliance	Contract-based Alliance	Outsourcing.
PSP	Problem Structure (PS) Well-Structured → Ill-Structured	-	-	-
PSP	Complexity(COM) Simple → Complex	- (+)[*]	- (+)[*]	-
PSP	Decomposability (DEC) Decomposable → Non-Decomposable	-	-	-
KBV	Existing Knowledge-base (EKB) Little Knowledge → Complete Knowledge	-	-	-
KBV	Codifiability (COD) Codifiable → Non-Condifiable	-	-	-
KBV	Teachability (TEA) Teachable—Non-Teachable	-	-	-
KBV	Socially-distributed Knowledge (SDK) Non socially-distributed (personal) → Highly socially distributed	-	-	-
TCE	Demand Uncertainty (DU) low demand uncertainty → high demand uncertainty	-	-	-
TCE	Human Asset Specificity (HAS) Low human asset specificity → high human asset specificity	-	-	-
TCE	Physical Asset Specificity (PAS) Low physical asset specificity → high physical asset specificity	-	-	-
TCE	Appropriability (AP1) Non-appropriable → highly appropriable	-	-	-
TCE	Appropriability (AP2) Non-appropriable → highly appropriable	-	-	-

[ǂ] The multinomial logit model is discussed in section 4. The hypotheses here are expressed in terms of the signs of β_{2k} (equity-based alliance), β_{3k} (contract-based alliance), and β_{4k} (outsourcing) in equation (4), where the k subscript corresponds to the explanatory variable under consideration. A negative (positive) β_{jk} gives a negative (positive) entry in the table. The 'hybrid' view of alliance also dictates that $\beta_{2k}>\beta_{3k}>\beta_{4k}$,.

[*] Alternative hypothesis, stating that *the_more complex a problem is, the more likely that the problem solving will be organized by alliance rather than by in-house, ceteris paribus.* By contrast, the default hypothesis states that *the more complex a problem is, the more likely that the problem solving will be organized in-house rather than by alliance, ceteris paribus.* Hypotheses regarding other variables can be formulated verbally in the same manner..

3. Empirical Setting

3.1 Data Collection

Data were collected by survey administered by structured interview. Some of the questions are adapted from previous studies (e.g., Kogut & Zander, 1993) whilst others are originally constructed to capture information on certain underexplored variables, in particular variables associated with the PSP. Obtaining responses from executives is often problematic with a survey, and the response rates for R&D related surveys are typically low (Mairesse *et al.*, 2010). Given this, a private market research company with strong business connections to the targeted industry was contracted to help distribute the questionnaire and to conduct part of the interviews.

In the survey, three types of information were collected. First, respondents were asked to give examples, based on the provided definitions, of the organization modes of their R&D projects involving an international element[4]. Secondly, respondents were asked to evaluate various attributes of these R&D projects using a pre-defined five point Likert scale. Thirdly, additional background information regarding the reported R&D project and the firm was also collected.

To control for inter-industry differences, the sectoral coverage of the study was confined to the consumer electronics industry, which includes (a) PC and peripherals, (b) mobile handset and other personal communication devices, and (c) household appliances and audio/video equipment.

The target response group of the survey were corporate informants with knowledge of their company's project-level R&D activities, including corporate executives in charge of R&D, R&D directors, R&D project managers, senior R&D researchers, etc.

The survey followed a rather standard procedure. The consultancy company complied from their database a list of consumer electronics companies that might have participated in international R&D[5]. Companies on the list were randomly selected, with a senior personnel in each selected company then being tentatively contacted by telephone to enquire into the possibility of survey participation. If rejected, the surveyors moved on to the next company on the list until the pre-set sample size[6] was reached. In total 96 companies were contacted, with 50 agreeing to participate in the

[4] An international R&D project is defined as one that involves cooperation with a foreign partner, is undertaken in a foreign location, or is intended mainly to serve a foreign market.

[5] Given that small companies are less active in R&D (Acs and Audretsch, 1991), an annual turnover of $2 million was (arbitrarily) set as the threshold for choosing candidate companies.

[6] With reference to studies of similar nature and theme, and given the budget constraint, the minimum sample size was set at 140 R&D projects.

survey. From the 50 companies, 111 people were interviewed, and they provided detailed information on 142 international R&D projects.

3.2 General Industrial Background

There is little systematic information regarding the overall status of international R&D activities in the Chinese consumer electronics industry. Nevertheless, the following information revealed by previous studies can be used as a benchmark to evaluate the representativeness of our sample. Prior studies (e.g., Zhou *et al.*, 2010) reveal that most of the manufacturing activities in this industry are highly concentrated in the following three mega-city regions: the Pearl River Delta (centered around Shenzhen and Dongguan), and, to a lesser extent, the Yangtze River Delta (centered around Shanghai and Suzhou), and the Bohai-Rim (centered around Beijing and Tianjin). The location of R&D activities in this industry is somewhat different. In the past two decades China's manufacturing sector in general, and consumer electronics industry in particular, has witnessed the rapid globalization of innovation activities, with MNCs being widely recognized as the key driving force. (Boutellier *et al.*, 2008). A large proportion of R&D activity in this industry can be related to R&D presence of MNCs in China, either independently or in cooperation with indigenous firms and institutions (Li *et al.*, 2005). The innovative dynamics and the interaction between foreign and indigenous firms have been well-documented, both for the segment of PC and peripherals (e.g. Chen, 2004; Ernst, 2008), and for the segment of mobile handset and personal communication devices (e.g., Fan, 2006). Studies suggest that foreign R&D facilities in China are predominantly concentrated in Beijing and Shanghai[7], with Tianjin, Suzhou and the Southern Cantonese cities of Guangzhou and Shenzhen as secondary locations (Boutellier et al., 2008). Moreover, it is found that R&D units with a research mission tend to locate themselves in Beijing, whereas development laboratories prefer to choose a location in, or in the vicinity of, Shanghai (Zedtwitz, 2004).

Given the above background information, we believe the current sample is more or less representative of the population in terms of geographic and sectoral distribution, type of ownership, etc. (see Table 2).

[7] According to Boutellier et al. (2008), by September 2006, 67% of the 495 foreign R&D laboratories in China were located in Beijing and Shanghai.

Table 2: Distribution of the Sample by Sector, Location, Nature of Ownership and Organization Mode

By Sector			By Nature of Ownership		
Sector	**Number of Cases**	**%**	**Nature of Ownership**	**Number of Cases**	**%**
PC and Peripherals	32	23	Chinese Firm	38	27
Mobile Handset and Other Communication Devices	50	35	Fully-owned Subsidiary of a Foreign Firm	87	61
White Goods and Brown Goods	60	42	Sino-foreign Joint Venture	17	12
By Location			**By Organization Mode**		
Location of the R&D Project	**Number of Cases**	**%**	**Organization Mode**	**Number of Cases**	**%**
Beijing-Tianjin (Bolai Rim)	21	15	In-house	61	43
Shanghai-Suzhou(Yangtze River Delta, YRD)	88	62	Equity-based Alliance	24	17
South China (Guangdong & Fujian)	27	19	Contract-based Alliance	34	24
Other Locations	6	4	Outsourcing	23	16

3.3 The Variables: Definition and Measurement

3.3.1 Dependent Variable

In this study, the dependent variable, ***organization mode***, is an unordered discrete variable classified into three broad categories: in-house, collaborative arrangements (alliances) and outsourcing (arm's-length like contract) (Robertson *et al.*, 1998). When contract-based and equity-based collaborative arrangements are treated separately (Pisano, 1989), a total of four organization modes results, namely:

In-house — the firm undertakes the R&D project internally.

Outsourcing — the firm contracts out an R&D project to some other organization to find a solution for a technological problem. When a project is so organized it is essentially a 'cash-for-technology' exchange approximating an arm's-length contract, with the solution typically being of a 'ready-to-use', 'off-the-shelf' nature which can be integrated into the firm's existing system of operation with little adaptation.

Collaborative arrangements (***alliances***) —which allows for a wide variety of 'hybrid' organization modes. In this study we distinguish between ***contract-based*** and ***equity-based collaborative arrangements***. In the first case no equity exchange is involved, whereas in the second case partner firms refer to some equity-based arrangement as an umbrella structure to support their joint R&D projects, either setting up a joint venture and undertaking joint R&D projects in this new legal entity, or alternatively taking/cross-taking minority equity stakes to support such projects.

Table 2: The Organization Modes of the Firms' R&D activities

Organizational Mode	In-house	Collaborative Arrangements		Outsourcing (Arm's-length Like Contract)
		Equity-based Collaborative Arrangement	Contract-based Collaborative Arrangement	
Examples	Wholly-owned subsidiary (either manufacturing , or R&D oriented)	Production joint venture (in which joint R&D projects are undertaken); R&D joint venture	Co-development contract; Bilateral licensing	Unilateral licensing; R&D contract; OEM

3.3.2 *Independent Variables*

All independent variables are measured using a five point Likert scale (see Table 1).

Problem Structure (PS) Following Macher (2006), a well-structured problem is defined as one with a clear boundary of relevant knowledge sets, the interactions amongst which are well understood, so that there are explicit and widely accepted approaches for solving the problem. Conversely, for an ill-structured problem, the boundary of relevant knowledge sets is ambiguous, and the interactions amongst these sets are poorly understood, so that no widely-accepted approach for solving the problem exists.

Complexity (Intensity of Knowledge Set Interaction) (COM) In this study, complexity (intensity of knowledge set interaction) and decomposability are treated as separate variables. A simple problem is defined as one involving few knowledge sets and a low level of interactions/interdependences amongst them. Conversely, a complex problem involves a large number of knowledge sets and extensive interactions/interdependences.

Decomposability (DEC) A decomposable problem is defined as one that can be divided into sub-problems; each drawing on rather specialized knowledge so that it can be solved quite independently. Conversely, the knowledge sets interactions within a non-decomposable problem are so extensive that it is infeasible to define and solve sub-problems in a way that offers predictable advantages over random trials. For such problems, if a solution is to be found it has to be an overall solution.

Existing Knowledge-Base (EKB) A firm's existing knowledge base for a given R&D project is defined as the extent to which a firm possesses ***all*** the relevant knowledge/capabilities required to solve the problem at the time of project initiation.

Knowledge Tacitness Following Zander and Kogut (1995), knowledge tacitness is operationalized by the two dimensions of **codifiability(*COD*)** and **teachability (*TEA*)**. Codifiability is defined as the extent to which it is easy to find/prepare relevant reference materials (e.g., books, blueprints, or manuals) in order to provide a new team member with most of the critical knowledge in an accessible way. Teachability is defined as the extent to which it is easy for a new team member to learn, by working with, and being mentored by, a skilled team member, the core knowledge and skills required to solve the problem.

Social Distribution of Knowledge (SDK) The degree of social distribution of knowledge is defined as the extent to which the knowledge required to solve the problem is possessed by one or a few individual experts, as opposed to being widely distributed amongst a group of experts, so that no single expert can solve the problem.

The definitions of the following TCE variables are rather standard.

Demand Uncertainty (DU) Demand uncertainty (Robertson *et al.*, 1998) is defined as the difficulty of forecasting the future demand for the product/service to which the R&D project under consideration is intended to contribute.

***Human Asset Specificity* (*HAS*) *and Physical Asset Specificity* (*PAS*)** In this study human asset specificity is defined as the extent to which the skills and knowledge developed/accumulated in the R&D project under consideration are useful outside the project. Physical asset specificity is defined as the extent to which the investment in physical assets to support the R&D project under consideration can be redeployed outwith the project.

Appropriability (AP1 and AP2) In this study the appropriability of the relevant knowledge is defined as (AP1) the extent to which the R&D project under consideration can be easily imitated by an outsider (e.g., by reverse engineering or inventing around), and (AP2) the extent to which the departure of one or a few key R&D team members to a competitor would lead to substantial leakages of relevant knowledge to that competitor.

4. Multinomial Analysis of the Organization Choices

We start by assuming that the probability of project *i* being organized by mode *j* is given by

$$P_{ij} = \frac{e^{V_{ij}}}{\sum_l e^{V_{il}}} = \frac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}} \tag{1}$$

where x_i is a vector of characteristics of the i^{th} R&D project and the β_j are unknown parameter vectors to be estimated. The second expression in (1) defines the multinomial logit model. Parameter estimation is typically, and is here, maximum likelihood estimation with the first vector β_1 set at zero to ensure identification. Given β_1 = 0 we have $P_{ij}/P_{i1} = \exp(x_i'\beta_j)$ and the log-odds ratios

$$\ln\left[\frac{p_{ij}}{p_{i1}}\right] = x_i'\beta_j \qquad j = 2,\ldots \tag{2}$$

Differentiation of the second expression in (1) gives

$$\frac{\partial P_{ij}}{\partial x_{ik}} = P_{ij}(\beta_{jk} - \bar{\beta}_{k(i)}) \tag{3}$$

where $\bar{\beta}_{k(i)} = \sum_{l=1}^{J} \beta_{lk} P_{il}$ is a probability weighted average of β_{lk} over *l*. The derivative in (3) varies with x_i via P_{ij} and does not necessarily have the same sign as β_{jk}, so that the effect of changing x_{ik} is not obvious. On the other hand (2) gives

$$\frac{\partial ln(P_{ij} / P_{i1})}{\partial x_{ik}} = \beta_{jk} \tag{4}$$

so that an increase in x_{ik} increases (decreases) P_{ij} / P_{i1}, the likelihood of mode *j* relative to mode 1, when β_{jk} is positive (negative). The slightly more general

$$\frac{\partial ln(P_{ij} / P_{im})}{\partial x_{ik}} = \beta_{jk} - \beta_{mk} \tag{5}$$

allows the likelihood of mode *j* relative to mode *m* to be considered.

The derivative in (4) leads to an interpretation of β_{jk} as the proportionate change in P_{ij} / P_{i1} when x_{ik} increase by one unit. A related interpretation is based on

$$\frac{P_{ij}}{P_{i1}} = \exp(x_i'\beta_j) \quad j = 2,\ldots \tag{6}$$

and on $\exp(\beta_{jk})$ as the implied multiplication when x_{ik} increases by one unit. The implied proportionate change in P_{ij} / P_{i1} is then $\exp(\beta_{jk}) - 1$. The value of $\exp(\beta_{jk})$ is reported as RRR (relative risk ratio) in table 3. Subtraction of one and multiplication by one hundred then gives the percentage change in P_{ij} / P_{i1} implied by a unitary change in x_{ik}.

4.1 Multinomial Logit Estimation Results

Using the 142 sample observations, we estimate a multinomial logit model explaining the choice between in-house, equity-based alliance, contract-based alliance, and outsourcing, with in-house being the base outcome. Table 3 presents the parameter estimates.

Table 3: Multinomial Logit Estimation Results

	2 (Equity-based Alliance)			3 (Contract-based Alliance)			4 (Outsource)		
	Predicted Sign	*Coef. (Std. Err.)*	*RRR (Std. Err.)*	*Predicted Sign.*	*Coef. (Std. Err.)*	*RRR (Std. Err.)*	*Predicted Sign.*	*Coef. (Std. Err.)*	*RRR (Std. Err.)*
const		2.692 (4.002)			14.408 *** (4.281)			19.524 *** (5.048)	
PS	-	0.094 (0.514)	1.099 (0.564)	-	0.106 (0.494)	1.112 (0.549)	-	-0.927 (0.651)	0.396 (0.258)
COM	- (+)[ǂ]	1.385 ** (0.575)	3.995 (2.297)	- (+)[ǂ]	0.769 (0.541)	2.157 (1.168)	-	-0.946 (0.782)	0.388 (0.304)
DEC	-	-1.547 ** (0.661)	0.213 (0.141)	-	-1.090 * (0.627)	0.336 (0.211)	-	-0.738 (0.873)	0.478 (0.418)
EKB	-	-1.908 *** (0.526)	0.148 (0.078)	-	-2.259 *** (0.511)	0.104 (0.053)	-	-2.965 *** (0.611)	0.052 (0.031)
COD	-	-0.365 (0.434)	0.694 (0.302)	-	0.004 (0.437)	1.004 (0.439)	-	0.205 (0.568)	1.227 (0.696)
TEA	-	-0.110 (0.453)	0.896 (0.406)	-	0.206 (0.387)	1.228 (0.475)	-	-0.082 (0.567)	0.921 (0.523)
SDK	-	-0.093 (0.289)	0.911 (0.264)	-	-0.750 *** (0.293)	0.472 (0.138)	-	0.218 (0.412)	1.244 (0.512)
DU	-	-0.111 (0.375)	0.895 (0.335)	-	-0.168 (0.336)	0.845 (0.284)	-	0.430 (0.500)	1.537 (0.769)
HAS	-	-0.539 (0.473)	0.584 (0.276)	-	-0.426 (0.495)	0.653 (0.323)	-	-0.094 (0.768)	0.911 (0.699)
PAS	-	0.266 (0.446)	1.304 (0.582)	-	-0.440 (0.426)	0.644 (0.274)	-	-1.505 ** (0.671)	0.222 (0.149)
AP1	-	0.535 (0.381)	1.708 (0.651)	-	0.026 (0.342)	1.026 (0.351)	-	0.292 (0.513)	1.338 (0.687)
AP2	-	0.829 * (0.480)	2.290 (1.099)	-	-1.137 ** (0.457)	0.321 (0.147)	-	-1.053 * (0.631)	0.349 (0.220)

[ǂ] alternative hypothesis

Table 4: Classification Table

		Predicted				*Percentage Correct*
		1	2	3	4	
Actual	1	49	4	4	4	80.3%
	2	9	4	4	7	16.7%
	3	9	0	19	6	55.9%
	4	2	1	1	19	82.6%
Overall Percentage						64.1%

Equity-based alliance

For this alternative four variables are significant at the 10% level or better, three (EKB, COM, DEC) being KBV variables and one (AP2) being a TCE variable.

The coefficient of EKB is negative and significant at the 1% level, suggesting that when a firm has increasingly more complete relevant knowledge, it is more likely that the problem solving will be organized in-house rather than by alliance.

The coefficients for COM and DEC are both significant at the 5% level. The positive (negative) COM (DEC) coefficient suggest that, *ceteris paribus*, equity-based alliance is increasingly preferred to in-house as problem complexity increases, and in-house is increasingly preferred to equity-based alliance as problem non-decomposability increases.

AP2 is the remaining significant variable, with the positive coefficient implying that a larger AP2 value increases the relative probability of choosing equity-based alliance over in-house. This result is at odds with theoretical prediction, as internal organization is generally believed to be the most efficient mode for overcoming the appropriability problem. Notice that AP2 is also significant, but with a negative coefficient, in the estimation results relating to contract-based alliance.

Contract-based Alliance

For this alternative four variables are significant at the 10% level or better, three (EKB, SDK and DEC) being KBV variables and one (AP2) being a TCE variable.

SDK is significant at the 1% level for contract-based alliance but is ***not*** significant for equity-based alliance. The RRR values indicate that a unitary increase in SDK reduces the relative probability of choosing contract-based alliance and equity-based alliance (over in-house) by 52.8% and 8.9% respectively. Therefore, when an R&D project involves highly socially distributed knowledge, alliance in general, and contract-based alliance in particular, is less likely to be chosen over in-house. COM is not significant for contract-based alliance but is, at the 5% level, for equity-based alliance. The RRR values indicate that a unitary increase in COM increases the relative probability of choosing contract-based (equity-based) alliance over in-house by 115.7% (299.5%). Thus the effect of COM on contract-based alliance is both smaller and less significant than that on equity-based alliance. These results suggest that as the complexity of the problem to be solved increases alliance is increasingly more likely to be chosen over in-house, with a preference for equity-based alliance rather than contract-based alliance. Given that, unlike equity-based alliances, contract-based alliances do not generally have access to such governance apparatus as high bandwidth communication channels, collocation of team members, and centralized administrative coordination, and that equity-based alliances are supported by enhanced incentive alignment associated with shared equity, it could be argued that of the two types of alliance, contract-based alliance is particularly not suitable for mobilizing socially distributed knowledge, and equity-based alliance is far more effective in dealing with more complex problem.

The coefficient of AP2 is negative and significant at the 5% level. As noted earlier, its sign is opposite to that for equity-based alliance, suggesting that the two types of alliance differ dramatically in terms of the ability to cope with appropriability problems. Theoretically, the results might be ***partially***[8] justified on two grounds. First, equity-based alliances are supported by shared ownership, helping to moderate opportunistic inclinations of participating parties. Secondly, the administrative structure that comes with shared ownership also furnishes an equity-based alliance with enhanced administrative controls over unintended leakage of appropriable knowledge. These arguments point to a greater effectiveness of an equity-based alliance in dealing with appropriability problems.

Outsourcing

For this alternative three variables are significant at the 10% level or better, one (EKB) being a KBV variable and two (PAS, AP2) being TCE variables. Seemingly, transaction cost considerations play a more decisive role for the choice of outsourcing than for the other alternatives.

[8] The positive AP2 coefficient for equity-based alliance is inconsistent with theory and difficult to rationalise.

The coefficient of EKB is again negative and significant at the 1% level, suggesting that a higher level of existing knowledge base favours the choice of in-house over outsourcing[9]. Similarly, the negative coefficients of PAS and AP2 suggest that as the physical assets invested to support an R&D project become more specific, and that as the relevant knowledge becomes more appropriable, it is more likely that the project will be organized internally rather than by outsourcing.

In summary the model performs fairly well, with the overall 'hit rate' of 64.1% (see Table 4) being considerably higher than that of random prediction, 25%, and that implied by assigning all observations to the most common alternative, 43.96%. However, the poor 'hit rate' of 16.7% for the alternative of equity-based alliance should be noted.

Intuition suggests that the two types of alliance should not be combined given that the coefficients of AP2 are of different signs, that a higher COM value favours the choice of both types of alliance over in-house, but with the increased probability going mostly to equity-based alliance, and that a higher SDK value has a stronger, and more significant, negative impact on the probability of choosing contract-based alliance rather than equity-based alliance. In fact a more formal approach is possible since it can be shown that the equality of all elements of vectors β_i and β_j, excepting the constant, implies categories *i* and *j* can be combined. Thus twelve restrictions are required if the two types of alliance are to be combined. Two test statistics are readily available to test these restrictions. A likelihood ratio test, $\chi^2(12) = 18.17$, has a p value of 0.111, implying that the null can be accepted at the 10% significance level. On the other hand a Wald statistic, $\chi^2(12) = 25.48$, has a p value of 0.013, implying the null is rejected at the 10% and 5% significance levels. On balance the evidence is perhaps rather against the combining of the two types of alliance.

4.2 Predicted Probabilities and Marginal effects

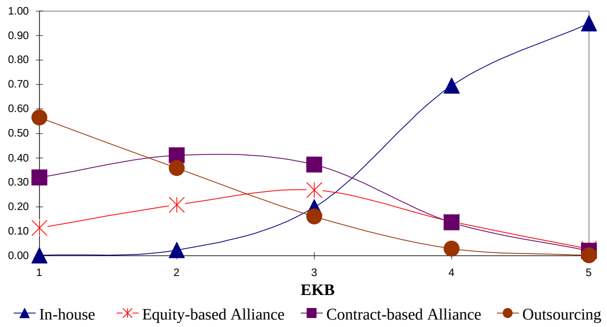
The above discussion considers probabilities relative to the base alternative of in-house so that is not clear how the absolute probabilities of the four alternatives are affected by the change of variables. Indeed, it is a straightforward exercise to calculate the predicted probability for each alternative at different values of the explanatory variables, as shown in Figure 1. For example, sub-figure 1-1 shows how

[9] For other comparisons equation (5) is required. For example the coefficient of EKB for the alternative of contract-based alliance (outsourcing) is -2.259 (-2.965). It follows that the coefficient of this variable in a choice between contract-based alliance and outsourcing is 0.762, so that a higher EKB value increases the relative probability of choosing contract-based alliance over outsourcing.

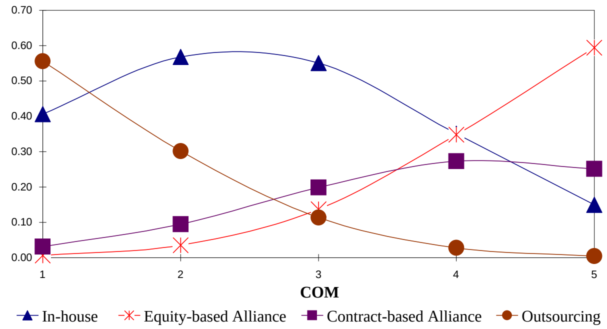
the four probabilities change as EKB varies from one to five, with the other variables at their sample means. The other sub-figures are similarly constructed[10].

[10] The variables chosen are those estimated to be significant in Table 3.

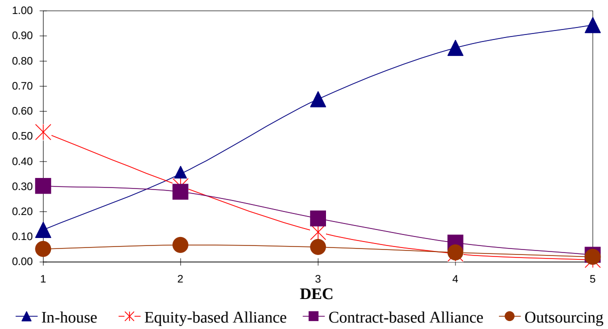
Figure 1: The Effects of the Point-by-Point Increase of Selected Variables on the Predicted Probability of Each Alternative



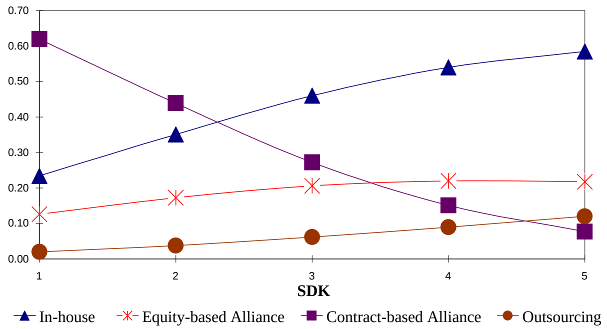
1



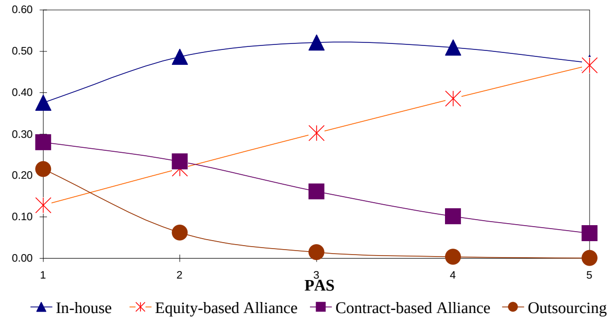
2



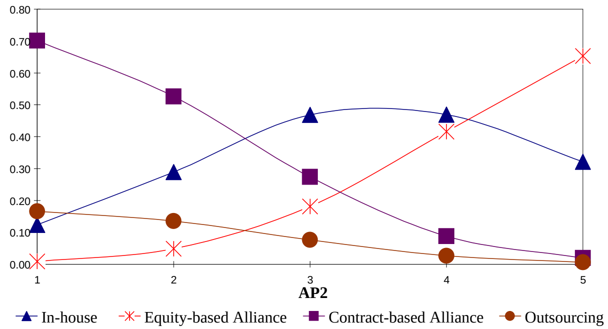
3



4



5



6

Figure 1-1 suggests the two types of alliance are similarly affected by variation in EKB, with an initially increasing, and finally decreasing probability. Outsourcing is the most likely alternative at low EKB and in-house is the most likely alternative at high EKB. For intermediate values of EKB alliance, in particular contract-based alliance, is most likely. Therefore, when a firm is confronted with a problem for which it has little background knowledge, outsourcing is most likely to be chosen as the organization mode, whereas with a high level of background knowledge, problem solving is most likely to be organised internally. Between these two polar situations alliances are most likely to be chosen, with a preference for contract-based alliance.

Figure 1-2 suggests that the probability of the equity-based alliance is more sensitive to variation in COM than is the probability of the contract-based alliance, with the first probability being substantially larger when COM equals five. Outsourcing is most likely to be chosen for solving problems of lowest complexity and equity-based alliance is most likely for solving the most complex problems. For problem of intermediate complexity, internal organization is the most likely choice.

In Figure 1-3 the probability of in-house increases substantially with DEC. At the same time the probabilities of either type of alliance decrease, with the impact of increasing DEC being more marked for equity-based alliance compared to contract-based alliance. DEC seems to have little impact on the probability of outsourcing.

In Figure 1-4 we find that SDK has a rather slight positive effect on the probability of equity-based alliance and a more pronounced negative effect on the probability of contract-based alliance. The probability of in-house increases monotonically with SDK. Overall, the results tend to suggest that to mobilize socially distributed knowledge, some sort of hierarchical structure is needed, whether it be a pure internal hierarchy or some other equity-based arrangement. An R&D project involving highly socially distributed knowledge is most likely to be organized internally.

Figure 1-5 shows that increasing PAS tends to increase the probabilities of in-house and equity-based alliance and decrease the probabilities of contract-based alliance and outsourcing. Its opposite impact on the two alliance probabilities serves to emphasise the distinctions between the two types of alliance. As argued within TCE, with the support of shared ownership, equity-based alliances can provide superior incentive alignment and better administrative controls, thus helping overcome problems of asset specificity more effectively than contract-based alliances (Anderson *et al.*, 1986). Our result tends to support such an argument.

Figure 1-6 suggests that AP2, another TCE variable, has broadly similar effects to PAS, with an increase in AP2 tending to increase the probabilities of in-house and equity-based alliance and decrease the probabilities of contract-based alliance and outsourcing. The results tend to support the view that in-house and equity-based alliance are more effective in coping with the appropriability problem than contract-based alliance or outsourcing (Oxley, 1997), for the same sort of reasons mentioned above. However, in Figure 1-6, equity-based alliance is twice as likely as in-house when AP2 equals to five. This result is at odds with the predictions of TCE theory, wherein hierarchy is viewed as the most effective mode for dealing with the appropriability problem.

4.3 Testing of the IIA Assumption

One frequently noted implication of the MLM is the *independence of irrelevant alternatives* (IIA) property, wherein probability ratios P_{ij}/P_{ik} are unchanged when alternatives are added or removed. If IIA were thought inappropriate on theoretical grounds then a different specification to the MLM would have to be considered. One such specification is the multinomial probit model (MPM)[11], although estimation of the MPM is very complicated for all but small *J*. In fact the Hausman and McFadden (HM) statistic (Hausman *et al.*, 1984) is frequently presented as a test of the IIA property after MLM estimation. It is based on a comparison of the MLM parameter estimates with the estimates obtained when choice categories are removed and estimation is repeated. We obtain[12] the results in Table 5, where each value is judged by reference to the $\chi^2(26)$ distribution since only 26 of the full set of 39 parameters are re-estimated when a single category is removed. Given this, none of the values in Table 4 leads to rejection of IIA. This conclusion takes the negative value to not indicate evidence against IIA[13], this seemingly being the most common approach. In fact Hausmann and McFadden (1984) mention an alternative calculation which is guaranteed to be positive and which has recently been advocated by Vijwerberg (2011). This alternative calculation[14] seems to leads to significant values and therefore raises doubts about the MLM. Notwithstanding this, we retain the MLM results.

---

[11] Both MLM and MPM are additive random utility models wherein utility $U_{ij} = V_{ij} + \varepsilon_{ij}$, with V_{ij} (ε_{ij}) being the deterministic (random) component of utility, and with the *j* witch lead to a maximum of the U_{ij} being selected by agent *i*. MLM and MPM differ in the assumptions made about the distribution of ε_{ij} across *i* and *j*. In either case, when discussing the choice of organization, the utility maximisation story might be recast in terms of cost minimisation.

[12] All the estimation is done using STATA which automatically presents the HM values of Table 5.

[13] Recall that a χ^2 cannot be negative.

[14] Programming is required here. We used GAUSS.

Table 5: Results of Hausman Tests of IIA Assumption

Omitted	chi2	Df	P>chi2	evidence
2	2.829	26	1.000	for H_0
3	-1.519	26	1.000	for H_0
4	5.339	26	1.000	for H_0

4.4 Discussion

Complexity, Decomposability and Problem structure

The empirical results suggest that problem complexity and decomposability are important shaper of a firm's R&D organization choice, while the effects of problem structure are less evident.

For both types of alliance DEC has a significantly negative coefficient, suggesting that non-decomposable problems are more likely to be solved in-house than by alliance because such problems are more effectively dealt with through the extensive knowledge exchange characteristic of internal organization. By contrast, the coefficient of COM is significant, and positive, only for equity-based alliance, suggesting, rather counterintuitively given general PSP arguments, that more complex problems are more likely to be solved by equity-based alliance rather than in-house.

Overall, the results are mixed. On the one hand, there is support for the PSP argument (Heiman & Nickerson 2004) that in-house is more effective for solving non-decomposable problems, and that the more hierarchical equity-based alliance is more likely to be chosen over contract-based alliance when problem solving complexity is high. On the other hand, the results indicate that COM and DEC's effects on the probability of choosing equity-based alliance are in opposite directions, contradicting the PSP view that they are two concomitant properties of the same factor (Nickerson and Zenger, 2004). Relatedly, it is also suggested that, contrary to the general PSP prediction, equity-based alliance is even more likely to be chosen over in-house to solve a more complex problem.

A Firm's Existing Knowledge Base

The results in Table 3 suggest that a firm's existing knowledge-base is the most important single explanatory variable. When a firm is confronted with a problem for which it has much (little) relevant knowledge, it tends to organize the problem solving internally (by outsourcing). Between these two extremes alliances are most likely to be chosen, with the contract-based alliance being the more preferred. These results are generally in line with the RBV and the bulk of empirical evidence in the RBV literature (e.g., Argyres, 1996; Bigelow *et al.*, 2008; Madhok, 2002; Poppo *et al.*, 1998), which clearly indicates that a firm's existing knowledge base has a strong independent effect on its organization choice.

Knowledge Tacitness and Social Distribution

In contrast to most existing relevant studies (e.g., Heiman *et al.*, 2004; Kogut *et al.*, 1993; Mowery *et al.*, 1996) the estimation results show that knowledge tacitness is not significant for any of the choices. Social distribution (embeddedness) of knowledge is however estimated to be a significant determinant for the choice between in-house and contract-based alliance, where the more socially distributed the knowledge is the more likely in-house is to be chosen as the organization mode. Further, it seems that of the two types of alliance, contract-based alliance is particularly unsuitable for mobilizing socially distributed knowledge. The results are broadly consistent with the 'received wisdom' of relevant theoretical (Langlois *et al.*, 1999) and empirical (e.g., Heiman *et al.*, 2004) literature.

Overall, the above results tend to suggest, tacitness in itself does not necessarily constitute a barrier to inter-firm knowledge transfer. Logically tacit knowledge can be knowledge embedded in a single mind, so that it can be mobilized on a personal level. A firm thus does not have to refer to formal governance mechanisms to access such knowledge, "learning by hiring away" will suffice (Chesbrough, 2003). By contrast socially-distributed knowledge has seemingly clearer governance ramifications as such knowledge, by definition, can only be mobilized on a collective level. We therefore suggest that future research should try to differentiate personal tacit knowledge from socially distributed tacit knowledge.

TCE Variables

Both in terms of the magnitude of effect and the level of significance, it appears that TCE variables are less important than the PSP and the KBV variables in the current sample. Both PAS and AP2 are significant, at the 5% level and 10% level respectively, for the choice between in-house and outsourcing, and AP2 is also significant, at least at the 10% level, for the remaining organizational choices. However the positive AP2 coefficient for the alternative of equity-based alliance is at odds with theoretical prediction and is, therefore, difficult to explain.

In summary it seems fair to conclude that each theoretical perspective receives some support from our results but that, in general, the various PSP and KBV variables are of more explanatory importance than the TCE variables.

5. Conclusions

This paper contributes to the PSP of the boundary determination of the firm, both theoretically and empirically. On the basis of a review of existing PSP literature it is argued that knowledge-set interaction and decomposability are conceptually distinguishable and should be treated as separate variables. With reference to other closely related literature, it is also argued that a firm's existing knowledge can be expected to be important in the organization of its problem solving activities, notwithstanding that this dimension has been ignored in the existing PSP literature.

In the empirical setting of the Chinese consumer electronics industry we examine the underlying determinants of a firm's organisation choice for its R&D (technological problem solving) activities. Existing knowledge base is found to be the most significant variable in explaining the choice. Problem complexity and decomposability are also found to be important, with their effects not always being in the same direction. Non-decomposability tends to favour the choice of in-house while complexity tends to favour the choice of equity-based alliance. These results seemingly support the argument that complexity and decomposability should be treated as separate variables. It also suggests that, as far as the costs and competencies of governing different types of problem solving are concerned, alliances are probably not 'hybrid' modes of organization. Finally, whilst some TCE variables are found to be significant for certain organization choices, the results are relatively more supportive of the PSP and the KBV than of TCE.

Reference

Acs ZJ, Audretsch DB. 1991. R&D firm size and innovative activity. In ZJ Acs, DB Audretsch (Eds.), *Innovation and Technological Change: An International Comparison*. University of Michigan Press: Ann Arbor

Anderson E, Gatignon H. 1986. Modes of Foreign Entry: A Transaction Cost Analysis and Propositions. *Journal of International Business Studies* **17**(3): 1-26

Argote L. 1999. *Organizational Learning: Creating, Retaining and Transferring Knowledge*. Kluwer Academic

Argyres N. 1996. Evidence on the Role of Firm Capabilities in Vertical Integration Decisions. *Strategic Management Journal* **17**(2): 129-150

Arrow KJ. 1974. *The Limits of Organization*. Norton: New York

Bigelow LS, Argyres N. 2008. Make-or-Buy Revisited: A Population-Wide Test of Transaction Cost Alignment. *Journal of Economic Behavior and Organization* **66**(3-4): 791-807

Boutellier R, Gassmann O, Zedtwitz Mv. 2008. *Managing Global Innovation: Uncovering the Secrets of Future Competitiveness* (3 ed.). Springer: Berlin

Brechbuhl H. 2006. Strategic Partnering: Managing Joint Ventures and Alliances. Tuck School of Business at Dartmouth: Hanoverm, NH

Chen S-H. 2004. Taiwanese IT firms' offshore R&D in China and the connection with the global innovation network. *Research Policy* **33**(2): 337-349

Chesbrough H. 2003. *Open Innovation: The New Imperative for Creating And Profiting from Technology*. Harvard Business School Press: Cambridge

Cohen WM, Levinthal DA. 1990. Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly* **35**(1): 128-153

Conner KR. 1991. Historical Comparison of Resource-Based Theory and Five Schools of Thought Within Industrial Organization Economics: Do We Have a New Theory of the Firm? *Journal of Management* **17**(1): 121-154

Conner KR, Prahalad CK. 1996. A Resource-based Theory of the Firm: Knowledge Versus Opportunism. *Organization Science* **7**(5): 477-501

Coombs R, Metcalfe JS. 2000. Organizing for Innovation: Co-ordinating DistributedInnovation Capabilities. In NJ Foss, V Mahnke (Eds.), *Competence, Governance,and Entrepreneurship*: 209-231. Oxford University Press: Oxford

D'Aveni RA, Ravenscraft DJ. 1994. Economies of Integration versus Bureaucracy Costs: Does Vertical Integration Improve Performance? *The Academy of Management Journal* **37**(5): 1167-1206

Demsetz H. 1988. The Theory of the Firm Revisited. *Journal of Law, Economics and Organization* **4**(1): 141-161

Ernst D. 2008. Can Chinese IT Firms Develop Innovative Capabilities Within Global Knowledge Network? In HS Rowen, MG Hancock, WF Miller (Eds.), *Greater China's Quest For Innovation*: 197-216. Shorenstein Asia Pacific Research Center and Brookings Institution Press: Stanford, CA

Ethiraj SK, Levinthal DA. 2004. Bounded Rationality and the Search for Organizational Architecture: An Evolutionary Perspective on the Design of Organizations and Their Evolvability. *Administrative Science Quarterly* **49**(3): 404-437

Fan P. 2006. Catching up through developing innovation capability: evidence from China's telecom-equipment industry. *Technovation* **26**(3): 359-368

Fernandes R, Simon HA. 1999. A study of how individuals solve complex and ill-structured problems. *Policy Sciences* **32**(3): 225-245
Foss NJ. 1996. Knowledge-based Approaches to the Theory of the Firm: Some Critical Comments. *Organization Science* **7**(5): 470-476
Gavetti G, Levinthal DA. 2000. Looking Forward and Looking Backward: Cognitive and Experiential Search *Administrative Science Quarterly* **45**(1): 113–137
Grant RM. 1996. Toward a Knowledge-based Theory of the Firm. *Strategic Management Journal* **17**: 109-122
Grant RM, Baden-Fuller C. 2004. A Knowledge Accessing Theory of Strategic Alliances. *Journal of Management Studies* **41**(1): 61-84
Hausman JA, McFadden D. 1984. Specification Tests for the Multinomial Logit Model. *Econometrica* **52**(5): 1219-1240
Hayek FAv. 1945. The Use of Knowledge in Society. *American Economic Review* **35**(4): 519-530
Heiman BA, Nickerson JA. 2002. Towards Reconciling Transaction Cost Economics and the Knowledge-based View of the Firm: The Context of Interfirm Collaborations. *International Journal of the Economics of Business* **9**(97-116)
Heiman BA, Nickerson JA. 2004. Empirical evidence regarding the tension between knowledge sharing and knowledge expropriation in collaborations. *Managerial and Decision Economics* **25**(6-7): 401-420
Hippel Ev. 1994. "Sticky Information" and the Locus of Problem Solving: Implications for Innovation. *Management Science* **40**(4): 429-439
Hsieh C, Nickerson JA, Zenger TR. 2007. Opportunity Discovery, Problem Solving and a Theory of the Entrepreneurial Firm. *Journal of Management Studies* **44**(7): 1255-1277
Jonassen DH. 2004. *Learning to Solve Problems: An Instructional Design Guide*. Pfeiffer/Jossey-Bass: San Francisco, CA.
Kauffman SA. 1993. *The Origins of Order: Self-Organization and Selection in Evolution*. Oxford University Press: Oxford
Kay NM. 1997. *Pattern in Corporate Evolution*. Oxford University Press: Oxford
Kogut B. 1988. Joint ventures: Theoretical and empirical perspectives. *Strategic Management Journal* **9**: 319-332
Kogut B, Zander U. 1992. Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology. *Organization Science* **3**(3): 383-397
Kogut B, Zander U. 1993. Knowledge of the Firm and the Evolutionary Theory of the Multinational Corporation. *Journal of International Business Studies* **24**(4): 625-645
Kogut B, Zander U. 1995. Knowledge, Market Failure and the Multinational Enterprise: A Reply. *Journal of International Business Studies* **26**(2): 417-426
Kogut B, Zander U. 1996. What do Firms Do? Coordination, Indentity and Learning. *Organization Science* **7**(5): 502-518
Langlois RN. 1992. Transaction-Cost Economics in Real Time. *Industrial and Corporate Change* **1**(1): 99-127
Langlois RN, Foss NJ. 1999. Capabilities and Governance: The Rebirth of Production in the Theory of Economic Organization. *Kyklos* **52**(2): 201-218
Leiblein MJ, Macher JT. 2009. The Problem Solving Perspective: A Strategic Approach to Understanding Environment and Organization. In JA Nickerson, BS Silverman (Eds.), *The Economic Institutions of Strategy*, Vol. 26: 97-120. Emerald: Bingley
Levinthal DA. 1997. Adaptation on Rugged Landscapes. *Management Science* **43**(7): 934-950

Li J-T, Yue DR. 2005. Managing Global Research and Development in China: Patterns of R&D Configuration and Evolution. *Technology Analysis & Strategic Management* **17**(3): 317-337
Macher JT. 2006. Technological Development and the Boundaries of the Firm: A Knowledge-Based Examination in Semiconductor Manufacturing. *Management Science* **52**(6): 826-843
Macher JT, Boerner C. 2012. Technological development at the boundaries of the firm: a knowledge-based examination in drug development. *Strategic Management Journal*: n/a-n/a
Madhok A. 2002. Reassessing the fundamentals and beyond: Ronald Coase, the transaction cost and resource-based theories of the firm and the institutional structure of production. *Strategic management journal* **23**(6): 535-550
Mairesse J, Mohnen P. 2010. Using Innovation Surveys for Econometric Analysis. In BH Hall, N Rosenberg (Eds.), *Handbook of The Economics of Innovation*, Vol. 2: 1130-1155. Elsevier: Amsterdam
Mowery DC, Oxley JE, Silverman B. 1996. Strategic Alliances and Interfirm Knowledge Transfer. *Strategic Management Journal* **17**: 77-91
Nelson RR, Winter SG. 1982. *An Evolutionary Theory of Economic Change*. The Belknap Press: Cambridge, MA
Nickerson JA, Zenger TR. 2004. A Knowledge-Based Theory of the Firm: The Problem-Solving Perspective. *Organization Science* **15**(6): 617-632
Oxley JE. 1997. Appropriability Hazards and Governance in Strategic Alliances: A Transaction Cost Approach. *Journal of Law, Economics, and Organization* **13**(2): 387-409
Penrose ET. 1955. Limits to the Size and Growth of Firms. *American Economic Review* **45**(2)
Pisano GP. 1989. Using Equity Participation to Support Exchange: Evidence from the Biotechnology Industry. *Journal of Law, Economics, and Organization* **5**(1): 109-126
Polanyi M. 1962. *Personal Knowledge: Toward a Post-Critical Philosophy*. Harper & Row: New York
Polanyi M. 1966. *The Tacit Dimension*. Routledge and Kegan Paul: London
Poppo L, Zenger T. 1998. Testing Alternative Theories of the Firm: Transaction Cost, Knowledge-based, and Measurement Explanations for Make-or-Buy Decisions in Information Services. *Strategic Management Journal* **19**(9): 853 -877
Robertson TS, Gatignon H. 1998. Technology Development Mode: A Transaction Cost Conceptualization. *Strategic Management Journal* **19**(6): 515-531
Simon HA. 1962. The Architecture of Complexity. *Proceedings of the American Philosophical Society* **106**(6): 467-482
Simon HA. 1973. The Structure of Ill Structured Problems. *Artificial Intelligence* **4**(3-4): 181-201
Simon HA. 1988. Scientific discovery as problem solving. In HA Simon, M Egidi, R Viale, R Marris (Eds.), *Economics, bounded rationality and the cognitive revolution*. Elgar
Simon HA. 1991. Organizations and Markets. *Journal of Economic Perspectives* **5**: 25-44
Vijverberg W. 2011. Testing for IIA with the Hausman-McFadden Test, *IZA Discussion Papers 5826*. Institute for the Study of Labor: Bonn
Williamson OE. 1985. *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting*. Free Press: New York

Williamson OE. 1991. Comparative Economic Organization:The Analysis of Discrete Structural Alternatives. *Administrative Science Quarterly* **36**: 269-296
Williamson OE. 1996. *The Mechanisms of Governance*. Oxford University Press: New York
Zander U, Kogut B. 1995. Knowledge and the Speed of the Transfer and Imitation of Organizational Capabilities. *Organization Science* **6**(1): 76-92
Zedtwitz MV. 2004. Managing foreign R&D laboratories in China. *R&D Management* **34**(4): 439-452
Zhang J, Baden-Fuller C, Mangematin V. 2007. Technological knowledge base, R&D organization structure and alliance formation: Evidence from the biopharmaceutical industry. *Research Policy* **36**(4): 515-528
Zhou Y, Sun Y, Wei YHD, Lin GCS. 2010. De-centering 'spatial fix'—patterns of territorialization and regional technological dynamism of ICT hubs in China. *Journal of Economic Geography* **11**(1): 1-32