Available online at www.sciencedirect.com
ScienceDirect
Technovation 27 (2007) 461–470
technovation
www.elsevier.com/locate/technovation

Creating new technology through alliances: An empirical investigation of joint patents

Changsu Kim[a], Jaeyong Song[b,*]

[a]College of Business Administration, Ewha Womans University, Seoul 120-750, Korea
[b]Strategy and International Management, Seoul National University, Seoul 151-742, Korea

Abstract

Why are some alliances more productive than others in terms of creating new technology? Using a novel measure of alliance performance, that is, joint patents, this study aims to tackle this question. Our results from the global pharmaceutical industry show that joint invention has an inverted U-shape relationship with a path-dependent technology base, with the level of joint patents initially increasing and then decreasing beyond a certain level of path dependence. The results also show that joint patents are more numerous when the alliance partners have had prior ties with each other. Overall, the finding suggests that creating new technology through alliances can be facilitated by ensuring the positive side of absorptive capacity, while avoiding its downside.

Keywords: Innovation; Alliances; Joint patents; Absorptive capacity

1. Introduction

Firms frequently use partnerships to acquire new technology (Powell et al., 1996), to pool complementary technologies (Teece, 1992), or to share the costs of exploiting a certain form of technology (Nakamura et al., 1996). In some rapidly evolving sectors, where the locus of proprietary knowledge is dispersed across companies and shifts quickly over time, the pooling of resources can lead to superior and faster technological development than would be possible internally (Doz and Hamel, 1997). In addition, collaborative R&D arrangements have been rapidly growing since the 1980s in high-tech industries (Hagedoorn, 2002).

Although the notion is well accepted that alliances can be useful for collaborative innovation, there is scant empirical evidence to support it. This lack of evidence reflects the difficulty in evaluating innovation output resulting from alliances. Recent studies of alliances, especially technology-based alliances, have investigated the association between alliances and innovation by looking at patents of individual firms as an indicator of innovation output (e.g. Ahuja, 2000; Stuart, 2000). However, output measured at the level of the individual firm is difficult to attribute to alliance-related activities because various exogenous factors influence the innovation output of individual firms. We attempt to remedy this situation by examining joint patents resulting from the collaborative efforts of alliances.

We argue that if firms engage formally in collaborative R&D, and if the output of the R&D is measurable by patent indicators, then patents which are co-assigned to both partners in an alliance should be good measures of innovative output resulting from the alliance. By definition, the co-assigned patent that we call the *joint patent* is assigned to and jointly owned by more than one inventor. To constitute a co-assigned patent, it is necessary that all the inventors involved make some contribution to the final invention. Here we focus our attention on inter-firm joint patents, tracking only patents owned jointly by two or more alliance partners.

According to Hicks and Narin (2001), co-assigned patents accounted for about 0.2% of US patents in the early 1980s, but the percentage rose to 1.4% in 1999. The

*Corresponding author. Tel.: +82 2 880 9080; fax: +82 2 878 3154.
E-mail addresses: cskim@ewha.ac.kr (C. Kim), jsong@snu.ac.kr (J. Song).

0166-4972/$ - see front matter
doi:10.1016/j.technovation.2007.02.007

percentage of co-assigned patents varies across sectors, with the two highest being 7% for biotechnology and 5.6% for pharmaceuticals. This salience of joint patents in these areas may be explained by the considerable scientific and technological interdependence among firms in pharmaceutical R&D. Modern pharmaceutical R&D is increasingly complex and demands an ever-widening range of skills. No single firm possesses all the knowledge, skills and techniques required (Powell et al., 1996). Accordingly, joint invention (and the collaboration that precedes it) often results from the need for complementary expertise.

This study is one of the early attempts to use joint patents as a measure of the innovation output of alliances. Hence, there are few studies which identify factors which predict the existence of joint patents. We therefore draw upon the literature on absorptive capacity and alliance learning, wherein it is argued that alliances provide a platform for learning and innovation. We focus on both the technological and relational aspects of alliance partners, and their effects on learning and innovation. Specifically, using patent citation data, we identify two key technology-related variables: path dependencies and pre-existing technology overlap between alliance partners. In addition, given many firms' aversion to sharing the ownership of proprietary technologies (Hagedoorn, 2003), we also introduce the variable of "repeated" alliance ties as a proxy for achieving a threshold level of trust, which is necessary to ease the appropriability risks of sharing proprietary technologies. Using a negative binomial regression model, we examine the impacts of these technological and relational variables on joint patenting in the context of the global pharmaceutical industry.

2. Theory and hypotheses

As a general rule, there are two ways of building R&D capabilities: through internal development or external acquisitions (Pisano, 1990). The extent to which firms can source external knowledge is determined, in part, by the nature of the knowledge to be sourced (Zander and Kogut, 1995) and by firm-specific capabilities (Cohen and Levinthal, 1990). State-of-the-art technologies are often developed from tacit knowledge that is built internally through experience (Cohen and Levinthal, 1990; Song, 2002) or "learning by doing" (Teece, 1982). Because this knowledge belongs to individuals within a firm and cannot be easily transferred across firms, organizational boundaries serve as "knowledge envelopes." Thus, valuable knowledge is much more likely to be diffused within an organization than outside it (Zucker et al., 1996). For example, Almeida et al. (2002) show that, in general, multinational firms transfer knowledge across countries more effectively than do firms within alliances or competitive markets because they not only have more internal mechanisms for knowledge transfer at their disposal, but can also use those mechanisms flexibly without worrying about misappropriation.

There are, however, several mechanisms that firms use to access external knowledge. Almeida (1996) highlights the advantages of co-location in technology-intensive regions. Similarly, Shan and Song (1997) show that foreign direct investments are used to source external knowledge that is embedded in foreign countries. Licensing agreements provide a formal means of acquiring external knowledge; they require firms which possess key knowledge to permit its transfer. Recently, Song et al. (2003) showed that engineer mobility is an important mechanism in inter-firm knowledge transfer, in a process that they call "learning by hiring."

Most importantly for our purposes, Mowery et al. (1996) point to the use of alliances in acquiring external knowledge. Verspagen and Duysters (2004) find that technology alliance networks indeed show small-world properties which are characterized by an efficient flow of information and knowledge. However, technology acquisition by alliance is not a substitute for, but a complement to internal development, as a new external technology brought into a firm builds upon existing internal technologies (Cohen and Levinthal, 1990). Researchers have identified an upsurge in R&D alliances since the 1980s (Hagedoorn, 1993, 2002). The most common reason given for the increasing popularity of collaborative R&D is that fewer firms are able to "go it alone" in technological development (Teece, 1992; Powell et al., 1996). In addition, alliances can speed up learning and innovation processes (Doz and Hamel, 1997). In these types of alliances, benefits can extend beyond the life of the alliance, as firms learn from their partners and increase their capabilities (Hamel, 1991; Mowery et al., 1996).

Inter-firm cooperation in the form of licensing, R&D contracts and joint ventures are of central importance especially to the pharmaceutical sector. For instance, 38% of new chemical entities approved by the FDA between 1963 and 1999 were based on licensing deals. In addition, the average number of biotechnology alliances formed per pharmaceutical company increased from 1.4 per year in 1988–1990 to 5.7 per year, per firm in 1997–1998 (Nicholson et al., 2002). In the context of the global pharmaceutical industry, we investigate the conditions under which alliances are more likely to produce joint patents. We develop hypotheses by focusing on both technological and relational aspects of alliances. When we develop hypotheses regarding technological aspects, we draw primarily on evolutionary economics (Nelson and Winter, 1982).

2.1. Path-dependent technologies and joint invention

Schumpeter (1961) argues that, in general, innovations arise from new combinations of existing technologies. This suggests that the creation of new technology does not occur in the absence of current technology. Evolutionary economics proposes that the search for new knowledge is often localized or path-dependent, i.e., it is influenced by a firm's experiences (Nelson and Winter, 1982). The organizational capability required for the generation and application of technology normally becomes embodied in a set of routines within a firm, which then shape and constrain further choices regarding technology development (Nelson and Winter, 1982). Technological "local searching" is thus produced by the smooth functioning of organizational routines (Stuart and Podolny, 1996).

The path-dependent accumulation of new knowledge leading to technological development reflects the areas of a firm's core competence (Leonard-Barton, 1992; Doz and Hamel, 1997), in which it has conducted a substantial amount of in-house R&D and has accumulated technology and capabilities. To some extent, each firm is influenced by the trajectory of its technological development in the past, in that the development of new technology requires the internally accumulated technology to have an absorptive capacity (Cohen and Levinthal, 1990). As such, internally accumulated technologies are positively related to a firm's ability to generate new technology, even jointly with other firms.

However, path-dependent technologies may manifest a sense of self-sufficiency and "inertia" (Nelson and Winter, 1982) or "rigidity" (Leonard-Barton, 1992). When firms perform well, they may be satisfied with their current programs of innovation and thus less motivated to access other firms' expertise to improve their own performance (Levitt and March, 1988). As organizations experience success, their routines and products become more standardized, and it may become more difficult and costly for them to integrate technologies from other firms. Moreover, under the conditions of uncertainty that often characterize innovation, the results of past searches become the natural starting points for new searches, and firms continue to build on their own established knowledge, thus becoming path-dependent (Nelson and Winter, 1982; Stuart and Podolny, 1996).

This path dependence impedes a firm's receptivity to external knowledge (Song and Shin, Forthcoming), by reducing the motivation to seek, recognize, and assimilate knowledge that may be too different from current practice (Song et al., 2003), thereby inhibiting the development of knowledge-sharing routines in alliances. In other words, path-dependent firms highly value knowledge that is close to existing technological and market conditions, and devalue more distant knowledge that is available outside of the firm. This practice can manifest itself in a "not-invented-here" syndrome (Levitt and March, 1988). Furthermore, successful external knowledge acquisition requires a change in internal organizational routines (Argyris and Schon, 1978); therefore, firms that have developed strong internal routines are less likely to be open to new knowledge brought in by alliance partners.

Based on this discussion, we can hypothesize that internally accumulated technologies at low to moderate levels of path dependence influence joint invention positively due to their absorptive capacities, but this relationship is negative at higher levels of path dependence due to the low motivation to source external knowledge from alliance partners.

H1. There is an inverted U-shape relationship between joint invention and the combined path dependence of alliance partners.

2.2. Technology overlap and joint invention

Variations in technology across firms are a result of the idiosyncratic development of their paths or trajectories (Cantwell, 1994). For instance, in the pharmaceutical industry, firms race toward the creation and commercialization of similar end products, but each firm takes a distinctive path toward that end. This explains the variation in technologies across firms, a variation that alliances seek to bridge. Furthermore, alliances offer learning opportunities that internal development does not, because external technology is not subject to the specificities of path dependence (Ahuja and Lampert, 2001). However, the cost of pooling and managing knowledge brought into a firm by alliance partners may be too high to bear unless the partners share some common ground in terms of knowledge (Cantwell and Barrera, 1998). Obviously, firms sharing similar knowledge and experience inherently will have an easier time working together (Inkpen, 2000; de Man and Duysters, 2005).

We use the term "technology overlap" to indicate the extent to which firms build on related technological antecedents (Mowery et al., 1996). Technology overlap between alliance partners can influence the level of knowledge sourcing from one to the other. Lane and Lubatkin (1998) showed that firms with greater overlap in basic technology have greater relative absorptive capacity, and hence are more likely to learn from each other. It follows that technological overlap between alliance partners is likely to make it easier for them to learn with and from each other and create new knowledge jointly. Thus, we expect that the extent of learning from and with partners increases with the amount of overlap in terms of knowledge.

However, when alliance partners are too similar, there is little that they can learn from and with each other (Mowery et al., 1998; Hansen, 1999). There may be an optimal amount of technology overlap between alliance partners that influences both the potential benefits (higher when these firms are technologically distant) and the ability to collaborate (higher when these firms are close). This reasoning can be applied as well to the case of creating new technology jointly. When alliance partners' existing technologies are too distant, the level of synergy might be lower due to the partner firms' inability to work with each other's technology. At the same time, if alliance partners' technologies are too similar, then a firm either has little value to add, or the cost of doing so is relatively high. Thus, we posit a non-monotonic relationship between technology overlap and joint invention, with the level of joint invention first increasing and then decreasing with increasing technology overlap.

H2. There is an inverted U-shape relationship between joint invention and the pre-existing technology overlap of alliance partners.

2.3. Prior alliance ties and joint invention

Establishing an alliance for the purpose of invention enables the creation of new technology through the combination of similar but still distinct technologies. Technology sharing is best achieved through wide-ranging, continuous, and intense interactions between parties (Kogut, 1988a). Through the history of their partnership, firms can learn about each other's ways of doing business, and interpret meaning from each other's actions. This is part of the process of developing relational routines that are necessary to create a successful alliance (Dyer and Singh, 1998). Firms that have worked together in the past will have basic understandings of each other's skills and capabilities (Heide and Miner, 1992), which provides the impetus for mutual learning. In addition, experienced partners can forgo the relationship-building processes that are necessary for partners working together for the first time (Inkpen, 2000).

Repeated working relationships can generate an initial base of inter-partner trust (Gulati, 1995; Hagedoorn et al., 2003). Although expectations of trust ultimately arise from individuals, it is possible to think of inter-firm trust in economic transactions (Zucker, 1986). The idea of trust emerging from repeated partnerships is based on the premise that through ongoing interaction, firms learn about each other, including how to understand and predict each other's patterns of behavior (Dyer and Chu, 2000). As knowledge between partners increases, information asymmetries decrease, thereby reducing behavioral uncertainty (Casciaro, 2003). Trust begins where prediction ends (Lewis and Weigert, 1985).

Alliances usually involve significant uncertainty about future costs and benefits due to the possibility of opportunistic behavior and the lack of clear relationships based on a single authority. Moreover, alliances entail a risk of technology leakage, as there are inherent risks of unilaterally losing proprietary technologies to the partner (Hladik, 1988) unless trust has been built between allies. The relational routines and trust that have been developed over time through prior partnership efforts reduce the fear of opportunistic behavior, allow for greater openness, and facilitate the coordination of each partner's respective technologies (Kale et al., 2000). Hence, we hypothesize a positive relationship between joint invention and prior alliance ties between partners.

H3. The prior ties of partner firms have a positive effect on their joint invention.

3. Research design

3.1. Sample and data

This study focuses on the pharmaceutical industry, an industry rich in information, for over a decade and a half, on alliances and technological developments. Co-development of new technologies is well accepted as a major motive of collaborative R&D efforts (Koza and Lewin, 1998). This is especially true in the pharmaceutical industry, where the technology is complex and expanding, where future revenue streams originate from current R&D, and where R&D is time-consuming, uncertain, and costly (Powell et al., 1996). Even established pharmaceutical firms must ally with, and learn from, technology start-ups and global competitors with complementary R&D strengths and strategies (della Valle and Gambardella, 1993).

The sample of allied firms in the pharmaceutical industry was drawn from the Securities Data Company (SDC) database. The SDC database provides archival information on alliance activities, types, and industries. The SDC obtains this information from publicly available sources, including SEC files, trade publications and national and international news and wire sources. Although the database goes back to 1985, the SDC appears to have initiated systematic data collection only around 1988. We started by building a list of all alliance cases in the pharmaceutical industry between 1988 and 1995, resulting in 2952 alliances.

Next, we obtained firm-level patent data from CHI Research Inc. CHI is internationally recognized as a leading research organization that specializes in the development and analysis of patent indicators (Bierly and Chakrabarti, 1996). CHI corrects for company re-namings due to mergers, acquisitions, spin-offs, etc., and reassigns patents accordingly. It allows one to trace patents consistently no matter what their current ownership structure. The CHI database covers 1025 companies (460 US and 565 non-US companies) that were selected due to the relatively large numbers of patents registered with the US patent office since the 1980s. Of the 1025 companies, 315 belong to Standard Industrial Classification (SIC) code 28—the chemical and pharmaceutical sector.

The CHI data was next compared and combined with the alliance data obtained from the SDC. The sample selection was as comprehensive as possible in that all possible firms resulting from the combination of the alliance (SDC) and patent (CHI) data sets were included. However, because we needed complete data on both alliances and patents, and our data was coming from two separate databases, the selection was restricted to alliances in which both parent firms belonged to the CHI database. Hence, the number of firms was considerably reduced. We identified 414 alliances (from the SDC database) involving 102 firms (from the CHI database) from 1988 to 1995. Although patent data was available up to the year 2001, we confined the alliance sample up to 1995 to ascertain

Table 1
Variables and measurement

Variable name	Definition	Measurement
Joint invention $_{(t+1\ \text{to}\ t+6)}$	Number of co-patents between firms *i* and *j* for the first 6 years after the alliance formation	Jointly filed (and assigned) patents
Path-dependent technologies$_{(t)}$	Self-citation ratio = (firm *i*'s self-citations/total firm *i*'s other citations) + (firm *j*'s self-citations/total firm *j*'s other citations)	Patent self-citation ratio
Technology overlap$_{(t)}$	Cross-citation ratio = (firm *j*'s patents cited by firm *i*'s patents/total firm *i*'s citations) + (firm *i*'s patents cited by firm *j*'s patents/total firm *j*'s citations)	Patent cross-citation ratio
Prior alliance ties$_{(t-5\ \text{to}\ t-1)}$	Number of alliances between firms *i* and *j* with a 5-year moving window	Prior ties
Alliance type$_{(t)}$	Set to 1 if the alliance is joint R&D agreements and 0 otherwise	R&D vs. other alliances
Alliance governance mode$_{(t)}$	Set to 1 if the alliance is equity joint ventures (JVs) and 0 otherwise	Equity JVs vs. non-equity contracts
Inter-sectoral pairs$_{(t)}$	Coded as chemicals and pharmaceuticals. Set to 1 if the alliance partners belong to different sub-sectors and 0 if they belong to the same sub-sector	Sub-sectoral composition
International alliances $_{(t)}$	Set to 1 if the alliance partners have different nationalities and 0 if they have the same nationality	International vs. domestic alliances

whether alliances produced any joint patents in the 6 years after the alliance formation. We chose the 6-year time frame based on the alliance life cycle (lasting between a few months to several years, depending on the alliance's success and maintained commitment) and the time lag between patent application and grant (typically 18–24 months).

3.2. Variables and measures

Table 1 lists all variables, dependent and independent, used in our study and described below.

We searched for alliances with joint patents in our alliance sample and counted the number of joint patents that each alliance had produced in the 6 years after the alliance formation. The total number of joint patents is used to measure our dependent variable, *joint invention*.

As for independent variables, the self-citation ratio is a measure of *path-dependent technologies*. Sorensen and Stuart (2000) and Song et al. (2003) used self-citations in a similar manner to evaluate path dependence. We calculated patent self-citations as the ratio of the number of self-citations to the total number of citations by each firm, and then pooled the ratios by firms *i* and *j*.[1]

A patent cross-citation ratio between firms *i* and *j* captures the extent to which firms *i* and *j* cite each other's patents. Thus, the cross-citation ratio reflects the degree to which firms *i* and *j* are researching in similar technological areas (Mowery et al., 1996), and is an indicator of the *technology overlap* between firms *i* and *j*.

Prior alliance ties are measured by the number of alliances between firms *i* and *j* in the 5 years prior to the focal alliance. The presence of prior alliance ties means that the tie occurring during the focal period is the repeated one. We used a 5-year moving window based on previous research, suggesting that the lifespan for alliances is usually no more than 5 years (Kogut, 1988b; Gulati, 1995). Because the SDC database on alliances prior to 1988 is far from complete, we consulted additional sources, such as LexisNexis, to count the prior ties.

We included controls for various alliance characteristics. We first controlled for the type of alliance. Given that R&D alliances are designed to generate new technology, we expected a higher level of joint invention in R&D alliances than other types of alliances. Some prior studies (e.g. Hagedoorn, 2002) defined R&D alliances broadly as partnerships where R&D is at least part of the purpose of the alliance. More narrowly defined here, R&D alliances refer to bilateral technology transfer modes such as joint R&D projects and R&D joint ventures. We coded the variable *alliance type* as 1, indicating R&D alliances (including only joint R&D projects and R&D joint ventures) and 0 for other alliances.[2]

We also controlled for *alliance governance structure*. From a learning perspective, equity joint ventures provide the highest level of partner interaction and are posited to be the most effective means of knowledge transfer (Mowery

[1]The variable—path-dependent technologies—is a firm-level construct. However, since we have a dyadic dependent variable, joint patents, we pooled the self-citation ratios of the partner firms to make it dyadic-like. However, this operationalization may be a problem when there exists a strong path dependence asymmetry between partners, and such asymmetry plays a role in the joint invention of alliances. Thus, we included the following asymmetry measure in the regression to control for the problem: absolute (self-citation ratio of firm *i*-self-citation ratio of firm *j*)/(self-citation ratio of firm *i* + self-citation ratio of firm *j*). In the regression, the asymmetry variable turned out insignificant for joint patenting. Including this variable together with our combined path dependence variable did not make significant changes in our regression results.

[2]Note that these other alliances may also have included R&D activity and thus may have generated patents.

et al., 1996; Anand and Khanna, 2000). The joint creation of new knowledge requires considerable commitment of time and effort, equal motivation from both firms, and appropriate control mechanisms (Kogut, 1988a). Comparatively, long-term equity joint ventures served best for those purposes. We coded 1 for alliances classified as equity joint ventures and 0 otherwise.

We controlled for sub-sectoral combinations of firms within the industry of the alliances. CHI Research (from which patent data was obtained) counts patent totals for particular firms and then groups them based on the firm's primary activity. Our firm sample consisted of two sub-sectors in SIC 28: chemicals and pharmaceuticals. We coded *inter-sectoral pairs* as 1 if the firms in an alliance dyad belonged to different sub-sectors, and 0 if they belonged to the same sub-sector. Pfeffer and Nowak (1976) explained that inter-organizational ties were the result of underlying resource dependence across industrial sectors, and they suggested that firms belonging to different niches (e.g. sectors) are likely to have greater interdependence than firms belonging to the same niche. From the absorptive capacity perspective, however, firms in the same sub-sector tend to have similar or compatible operating systems and practices, which makes it easier to evaluate, communicate, and coordinate their cooperative activities (Lane and Lubatkin, 1998).

Finally, we controlled for *international alliances*. The question as to whether or not an alliance outcome is affected by the fact that the partners originate in different nations has been inadequately addressed in past literature. On the one hand, international alliances, because they have different technology bases, are more likely to bring diverse resources and capabilities to the alliance table. To that extent, ceteris paribus, international alliances can create unique learning opportunities not typically available to firms originating from the same country (Zahra et al., 2000). On the other hand, international alliances also entail higher technology transfer costs and may be less effective in the joint effort of coordinating respective technologies. In addition, the partners' social links are more attenuated and weaker, if they exist at all, compared with alliances originating from the same country (Brannen and Salk, 2000). *A priori* the question remains open.

3.3. Method

Joint patents are rare, though they are becoming more frequent (Hagedoorn et al., 2003). Even in biotechnology, which always had a high rate of joint patents, public sector organizations (such as universities and government laboratories) are responsible for most of the growth in joint patenting (Hicks and Narin, 2001). Firms, in contrast, seem to have an aversion to sharing technologies through joint patenting (Hagedoorn, 2003). We traced joint patents among our 102 sample firms starting from 1996 to 2001, to count the number of joint patents after alliance formation. In the 6 years after alliance formation, 58 joint patents were produced by our alliance pairs. The number of joint patents for any alliance entity is a non-negative integer with a limited range, and therefore violates the assumptions of OLS—homoscedastic and normally distributed errors. Under these conditions, Poisson or negative binomial models are appropriate (Hausman et al., 1984). Unlike the Poisson model, the negative binomial model does not assume the mean-variance equality of the count-dependent variable. We tested for over-dispersion of the number of joint inventions, as suggested by Cameron and Trivedi (1990), and found an over-dispersion problem (the parameter estimates were more than 1.0 and significant). We thus employed the negative binomial model with the number of joint patents as a dependent variable.

4. Results

Table 2 presents the means, standard deviations, and correlations of the variables. The correlation matrix shows significant correlations between control variables. In particular, a dummy variable for alliance governance is negatively and significantly correlated with alliance type and the other two control variables. This may possibly have something to do with a bias in the equity joint venture sub-sample, where manufacturing and marketing activities predominated, as opposed to "upstream" activities such as joint R&D. To gauge potential biases from this control variable, we estimated the main models without including this variable. The results for hypothesis testing did not

Table 2
Means, standard deviations, and correlations for variables

Variable	Mean	Sigma	1	2	3	4	5	6	7
1. Joint invention	0.140	0.836	—						
2. Path-dependent technologies	0.727	0.222	0.112*	—					
3. Technology overlap	0.025	0.038	−0.022	0.017	—				
4. Prior alliance ties	0.205	0.495	0.063	0.0001	0.075	—			
5. Alliance type	0.302	0.459	0.131*	0.019	0.063	0.004	—		
6. Alliance governance mode	0.413	0.492	−0.045	−0.054	−0.065	0.088	−0.209*	—	
7. Inter-sectoral pairs	0.328	0.470	−0.012	−0.014	−0.108*	0.011	0.044	−0.242*	—
8. International alliances	0.618	0.486	0.012	−0.003	0.051	0.065	0.040	−0.250*	0.094

*$p<0.05$.

Table 3
Negative binomial estimates of joint invention

Variables	Model 1	Model 2	Model 3	Model 4
Path-dependent technologies		6.418** (2.173)	6.426** (2.180)	6.186** (2.084)
The square of path-dependent technologies		-14.770^{Ψ} (8.007)	-15.525^{Ψ} (8.107)	-13.658^{Ψ} (7.335)
Technology overlap			−10.148 (11.272)	−12.552 (11.191)
The square of technology overlap			13.228 (124.556)	38.056 (117.04)
Prior alliance ties				0.927^{Ψ} (0.516)
Alliance type	1.830** (0.606)	1.736** (0.604)	1.844** (0.614)	1.812** (0.588)
Alliance governance mode	−0.348 (0.566)	−0.167 (0.563)	−0.194 (0.562)	−0.274 (0.564)
Inter-sectoral pairs	−0.804 (0.645)	−0.787 (0.634)	−0.816 (0.630)	−0.498 (0.601)
International alliances	0.132 (0.609)	−0.104 (0.606)	−0.224 (0.615)	−0.358 (0.595)
Intercept	−2.557*** (0.699)	−7.052*** (1.747)	−6.776*** (1.759)	−6.895*** (1.724)
N	414	414	414	414
Alpha (α)	15.74**	11.57**	11.04**	9.43*
Log-likelihood Functions	−128.24	−121.87	−121.17	−119.40
Restricted log-likelihood	−199.95	−178.75	−174.54	−171.02
χ^2 (d.f. = 1)	143.42***	113.75***	106.74***	103.22***

Standard errors are in parentheses. $^{\Psi}p<0.1$ $^{*}p<0.05$ $^{**}p<0.01$ $^{***}p<0.001$

change. The results in Table 3 are thus based on models controlling for alliance governance.

In Table 3, we present four models from the negative binomial regression. Overall, the models are robust, showing significant χ^2 statistics (with d.f. = 1), and the α values are also significant, supporting a good fit of the binomial regression model with our data. The results (coefficients and levels of significance) are also consistent and stable across models.

As a baseline, Model 1 loads only the control variables. Among control variables, only the alliance type turned out to be significant. Alliances, as a strategic choice, can be viewed as either exploitative or explorative (Koza and Lewin, 1998). In an exploitation alliance, firms look for additional sources of revenue by improving and refining currently employed capital and assets. In exploration alliances, firms pursue innovation, diversification, or other risky activities to achieve long-term growth and viability through access to new resources and skills. One of the prototypical forms of exploration alliances is a joint R&D alliance, which is designed to generate new technology. Given that R&D alliances focus on the pursuit and creation of new technology, it is not surprising to find a higher level of joint invention in firms that formed R&D alliances.

Model 2 adds path dependence variables. Hypothesis 1 predicts an inverted U-shape relationship between joint invention and the ratio of path-dependent technologies. The results show that joint invention is positively related to path-dependent technologies ($p<0.05$) and negatively related to the square of them ($p<0.1$), thus supporting Hypothesis 1.

Model 3 adds technology overlap variables. According to Hypothesis 2, a pair of allied firms with a pre-existing technology overlap is more likely to produce joint patents, with diminishing and negative returns. This relationship was not proved by our results. *Ex post*, we speculate that technology overlap is less relevant in the case of co-development of new technology than the exchange or learning of existing technology.

Model 4 as a full model adds a prior partnership variable. The coefficient of prior alliance ties is positive and significant, thus supporting Hypothesis 3, that prior experience working together has a positive effect on joint invention. We conjecture that inter-firm trust, which is built through prior alliance relations, encourages alliance partners to share their proprietary technologies for joint invention. Overall, the significant improvement of the log-likelihood functions from −128.24 to −119.40 ($\chi^2 = 17.68$; $p<0.01$) suggests that adding technological and relational variables should result in a much better fitted model.

5. Conclusion and discussions

We began our search for jointly assigned patents on the premise that the inventive output that presumably occurs in an alliance should result in joint ownership. Previous work investigating coassignees of patents found that joint ownership of patents between firms is rare, except for cases involving individual inventors from universities and research laboratories (Hicks, 2000). It seems more likely that behind each joint patent is a unique and substantive story of firms coming to share technology despite their natural distaste for doing so. What, then, makes independent firms form alliances and file joint patents? We can make a simple assumption that the observed growth in joint patents is evidence of an increase in R&D collaborations. However, there is a danger of assuming that all partnerships lead to joint patents. A more realistic assumption is that only successful partnerships generate joint patents. Then we must ask, under what circumstances are alliances more successful in terms of generating joint patents?

Our results suggest that prior alliance experience between allies is one of the factors in providing an impetus for joint patenting. Alliances are designed to meet the goals both of individual firms and of the collective whole, and are successful when the value of collective outcomes exceeds the opportunity costs that are incurred by participants (Jarillo, 1988). If firms have worked together in the past, they will have a basic understanding about each other's collaborative ways. Furthermore, prior ties between alliance partners can generate an initial base of inter-partner trust. This is a process of developing the relational routines necessary for allies to proceed further to the joint ownership of technologies. A one-time partnership may not be enough to develop such relational routines. Working together repeatedly provides time for the development of relational routines and inter-partner trust which, in turn, provide an impetus for technology sharing and joint ownership.

Our data did not support the technology overlap argument, which points mainly at similarity benefits based on the feasibility and ease of knowledge transfer and acquisition. The problem of the similarity arguments is that an enhanced efficiency of cooperation that cannot come along with the diverse learning opportunity has little value. According to a resource-based view, alliance partners seek resources that are complementary to their own, and that resource complementarity leads to value creation (Grant and Baden-Fuller, 2004). Perhaps, similarity in resources provides fewer new skills to learn and thus may be used for exploitation rather than exploration.

When we developed hypotheses regarding technology, we drew primarily on evolutionary economics (Nelson and Winter, 1982). A key argument of evolutionary economics is the path-dependence argument: technology develops locally. In other words, firms search for new technologies in areas that enable them to build upon their established technology bases (Stuart and Podolny, 1996). As a result, technological development is always, to some extent, localized within firms and path-dependent (Cantwell, 1994). We used the self-citation ratio as a proxy for a path-dependent technology base, and hypothesized that a path-dependent, internally accumulated technology base facilitates the collective effort of joint invention. However, the relationship between path-dependent technology and joint invention is non-monotonic. Specifically, although path-dependent technology initially has positive effects on joint invention, this relationship turns negative as firms develop a sense of self-sufficiency and a tendency to look inward. At this point, path dependence negatively influences a firm's engagement in joint invention. Firms that have established a more solid, firm-specific technological trajectory are less willing to search for new technology outside their corporate boundary. Thus, the relationship between the level of path-dependent technologies and joint invention is an inverted U-shape, as supported by our regression results.

In addition to addressing a previously unexplored empirical question, this paper deepens our understanding of how a firm can learn with and from alliance partners. Our finding that the negative motivational effects of existing technological capabilities within a firm exceed the positive effects of absorptive capacity beyond a certain threshold level, has implications for research in the management of innovation, which stresses the importance of external knowledge. Although absorptive capacity is viewed as a source of competitive advantage (Cohen and Levinthal, 1990), most research that advances this perspective downplays the potential negative consequences of such capabilities. Because a firm with a strong existing knowledge base is more likely to have established idiosyncratic technological trajectories, and thus to exhibit path-dependent search behavior, its knowledge base may reduce its receptivity to externally sourced knowledge. Firms that fit this description face the challenge of balancing and building their own exploitative and exploratory abilities (March, 1991). Our result suggests that the fostering of invention through alliances can be facilitated by ensuring positive path dependence, and thus avoiding the limitations that arise from path dependence.

Our use of a joint patent variable as a measure of alliance performance deserves some explanation. One measure of innovative outcomes from alliances that has been used in the past is the change in the number of patents held by an individual firm. However, the link between the change in the number of patents and a specific alliance is tenuous at best, as attributing a change in a firm's patenting activity to any specific alliance is difficult (Steensma and Corley, 2000). Taking a different tack on patent data, Mowery et al. (1996) introduced patent citation-based measures of technology flow between firms, on the premise that an increase in citations is indicative of the degree to which the citing firm is acquiring technology-based capabilities from the cited firm. This measure of change in patent citations, compared to the measure of the number of patents, is more alliance-specific, since it is directly related to the two firms in an alliance. However, we note that citation typically takes place impersonally, and can be nothing more than the acknowledgement of the debt to prior technology which is available to be cited. Furthermore, the association between alliances and patent citations is more complex: depending on the motives and forms, participation in alliances may produce either an increase or decrease in the cross-citation ratio (Mowery et al., 1996).

We attempted to overcome these limitations by measuring joint patents subsequent to alliance formation. Presumably a joint patent involves a qualitatively different kind of interaction compared to that of a citation. Joint patenting is often a result of successful joint R&D collaboration, wherein researchers from different firms interact face-to-face, exchange their ideas, and solve problems jointly. Thus, joint patents between firms are interesting examples of collective innovation output arising from formal inter-firm collaboration. We argue that joint patents are better indicators of the difference in inventive output across alliances, compared to the number of patents filed or citation of patents by a single alliance partner. However, the joint patent measure is not without limitations. Inter-firm joint patenting is a rare event (Hicks and Narin, 2001). Alliances oftentimes do not lead to a joint patent (Hagedoorn et al., 2003). Most importantly, the indivisibility of single inventions from small scale and informal collaborations is responsible for the growth of joint patenting (Hagedoorn, 2003).[3] While recognizing the limitations, it is nevertheless generally accepted that inter-firm joint patenting signifies the completion of a cooperative R&D, and the opening of another step toward subsequent developments and commercialization.

This research suggests potentially fruitful venues for future research. That joint invention is a possible motive for collaborative arrangements is generally accepted in the alliance literature. Despite the well-accepted maxim that "invention breeds collaboration," few studies have examined whether "collaboration breeds invention." With emphasis on this causality, we argue that collaborative arrangements, if they are to produce anything of substance, should produce a joint invention, and the joint invention should result in joint ownership, i.e. a joint patent. Historically, joint patents are rare, but their numbers have increased in recent years, especially in the pharmaceutical industry, due to the increasing technological interdependence among firms in pharmaceutical R&D. However, only a much larger investigation that includes various industries could definitely establish the relationship between alliances and joint invention. Given the natural aversion of firms to sharing their intellectual property rights, including patents, and the recent increase in joint patents, the possibility of a relationship between collaborative arrangements and joint patenting deserves further investigation.

References

Ahuja, G., 2000. Collaboration networks, structural holes, and innovation: a longitudinal study. Administrative Science Quarterly 45, 425–455.

Ahuja, G., Lampert, C.M., 2001. Entrepreneurship in the large corporation: a longitudinal study of how established firms create breakthrough inventions. Strategic Management Journal 22, 521–543.

Almeida, P., 1996. Knowledge sourcing by foreign multinationals. Strategic Management Journal 17, 155–165.

Almeida, P., Song, J., Grant, R.M., 2002. Are firms superior to alliances and markets? An empirical test of cross-border knowledge building. Organization Science 13, 147–161.

Anand, B.N., Khanna, T., 2000. Do firms learn to create value? The case of alliances. Strategic Management Journal 21, 295–315.

Argyris, C., Schon, D.A., 1978. Organizational Learning. Addison-Wesley, Reading, MA.

[3]We would like to thank one of the referees of this journal for drawing our attention to this aspect of joint patenting.

Bierly, P., Chakrabarti, A., 1996. Determinants of technology cycle time in the US pharmaceutical industry. R&D Management 26, 115–126.

Brannen, M., Salk, J., 2000. Partnering across borders: negotiating organizational culture in a German-Japanese joint venture. Human Relations 53, 451–488.

Cameron, A., Trivedi, P., 1990. Regression based tests for overdispersion in the Poisson model. Journal of Econometrics 46, 347–364.

Cantwell, J., 1994. Transnational Corporations and Innovation Activities. Routledge, London.

Cantwell, J., Barrera, P., 1998. The localization of corporate technological trajectories in the interwar cartels: cooperative learning versus an exchange of knowledge. Economics of Innovation and New Technology 6, 257–290.

Casciaro, T., 2003. Determinants of governance structure in alliances: the role of strategic, task and partner uncertainties. Industrial and Corporate Change 12, 1223–1251.

Cohen, W.M., Levinthal, D.A., 1990. Absorptive capacity: a new perspective on learning and innovation. Administrative Science Quarterly 35, 128–152.

de Man, A-P., Duysters, G., 2005. Collaboration and innovation: a review of the effects of mergers, acquisitions and alliances on innovation. Technovation 25, 1377–1387.

della Valle, F., Gambardella, A., 1993. Biological revolution and strategies for innovation in pharmaceutical companies. R&D Management 23, 287–302.

Doz, Y.L., Hamel, G., 1997. The use of alliances in implementing technology strategies. In: Tushman, M.L., Anderson, P. (Eds.), Managing Strategic Innovation and Change. Oxford, New York.

Dyer, J.H., Chu, W., 2000. The determinants of trust in supplier-automaker relationships in the US, Japan, and Korea. Journal of International Business Studies 31, 259–285.

Dyer, J.H., Singh, H., 1998. The relational view: cooperative strategy and sources of interorganizational competitive advantage. Academy of Management Review 23, 660–679.

Grant, R.M., Baden-Fuller, C., 2004. A knowledge accessing theory of strategic alliances. Journal of Management Studies 41, 61–84.

Gulati, R., 1995. Social structure and alliance formation patterns: a longitudinal analysis. Administrative Science Quarterly 40, 619–652.

Hagedoorn, J., 1993. Understanding the rationale of strategic technology partnering: Interorganizational modes of cooperation and sectoral differences. Strategic Management Journal 14, 371–385.

Hagedoorn, J., 2002. Inter-firm R&D partnerships: an overview of major trends and patterns since 1960. Research Policy 31, 477–492.

Hagedoorn, J., 2003. Sharing intellectual property rights—an exploratory study of joint patenting amongst companies. Industrial and Corporate Change 12, 1035–1050.

Hagedoorn, J., Kranenburg, H., Osborn, R.N., 2003. Joint patenting amongst companies—exploring the effects of inter-firm R&D partnering and experience. Managerial and Decision Economics 24, 71–84.

Hamel, G., 1991. Competition for competence and inter-partner learning within international strategic alliances. Strategic Management Journal 12, 83–103.

Hansen, M.T., 1999. The search-transfer problem: the role of weak ties in sharing knowledge across organizational subunits. Administrative Science Quarterly 44, 82–111.

Hausman, J., Hall, B., Griliches, Z., 1984. Econometric models for count data with an application to the patents-R&D relationship. Econometrica 52, 909–938.

Heide, J.B., Miner, A.S., 1992. The shadow of the future: effects of anticipated interaction and frequency of contact on buyer-seller cooperation. Academy of Management Journal 35, 265–291.

Hicks, D., 2000. 360 degree linkage analysis. Research Evaluation 9, 133–143.

Hicks, D., Narin, F., 2001. Strategic research alliances and 360 degree bibliometric indicators. In: Proceedings from an NSF Workshop, pp. 133–45.

Hladik, K.J., 1988. R&D and international joint ventures. In: Contractor, F.J., Lorange, P. (Eds.), Cooperative Strategies in International Business. Lexington Books, Massachusetts, pp. 187–204.

Inkpen, A.C., 2000. Learning through joint ventures: a framework of knowledge acquisition. Journal of Management Studies 37, 1019–1043.

Jarillo, J.C., 1988. On strategic networks. Strategic Management Journal 9, 31–41.

Kale, P., Singh, H., Perlmutter, H., 2000. Learning and protection of proprietary assets in strategic alliances: building relational capital. Strategic Management Journal 21, 217–237.

Kogut, B., 1988a. Joint ventures: theoretical and empirical perspectives. Strategic Management Journal 9, 319–332.

Kogut, B., 1988b. A study of the life cycle of joint ventures. In: Contractor, F.J., Lorange, P. (Eds.), Cooperative Strategies in International Business. Lexington Books, Massachusetts, pp. 169–186.

Koza, M.P., Lewin, A.Y., 1998. The co-evolution of strategic alliances. Organization Science 9, 255–264.

Lane, P.J., Lubatkin, M., 1998. Relative absorptive capacity and interorganizational learning. Strategic Management Journal 19, 461–477.

Leonard-Barton, D., 1992. Core capabilities and core rigidities: a paradox in managing new product development. Strategic Management Journal 14, 95–112.

Levitt, B., March, J.G., 1988. Organizational learning. Annual Review of Sociology 14, 319–340.

Lewis, J.D., Weigert, A., 1985. Trust as a social reality. Social Forces 63, 967–985.

March, J.G., 1991. Exploration and exploitation in organizational learning. Organization Science 2, 71–87.

Mowery, D.C., Oxley, J.E., Silverman, B.S., 1996. Strategic alliances and interfirm knowledge transfer. Strategic Management Journal 17, 77–91.

Mowery, D.C., Oxley, J.E., Silverman, B.S., 1998. Technological overlap and interfirm cooperation: implications for the resource-based view of the firm. Research Policy 27, 507–523.

Nakamura, M., Shaver, J.M., Yeung, B., 1996. An empirical investigation of joint venture dynamics: evidence from US-Japan joint ventures. International Journal of Industrial Organization 14, 521–541.

Nelson, R.R., Winter, S.G., 1982. An Evolutionary Theory of Economic Behavior and Capabilities. Harvard University Press, Cambridge.

Nicholson, S., Danzon, P.M., McCullough, J., 2002. Biotech–pharmaceutical alliances as a signal of asset and firm quality. Working paper, Wharton School.

Pfeffer, J., Nowak, P., 1976. Joint ventures and interorganizational interdependence. Administrative Science Quarterly 21, 398–418.

Pisano, G.P., 1990. The R&D boundaries of the firm: an empirical analysis. Administrative Science Quarterly 35, 153–176.

Powell, W.W., Koput, K.W., Smith-Doerr, L., 1996. Interorganizational collaboration and the locus of innovation: networks of learning in biotechnology. Administrative Science Quarterly 41, 116–145.

Schumpeter, J., 1961. The Theory of Economic Development. Oxford University Press, London.

Shan, W., Song, J., 1997. Foreign direct investment and the sourcing of technological advantage: evidence from the biotechnology industry. Journal of International Business Studies 27, 267–284.

Song, J., 2002. Firm capabilities and technology ladders: sequential foreign direct investments of Japanese electronic firms in East Asia. Strategic Management Journal 23, 191–210.

Song, J., Shin, J., Forthcoming. Paradox of technological capabilities: a study of knowledge sourcing from host countries of overseas R&D operations. Journal of International Business Studies.

Song, J., Almeida, P., Wu, G., 2003. Learning-by-hiring: when is mobility more likely to facilitate inter-firm knowledge transfer? Management Science 49, 351–365.

Sorensen, J.B., Stuart, T.E., 2000. Aging, obsolescence, and organizational innovation. Administrative Science Quarterly 45, 81–112.

Steensma, H.K., Corley, K.G., 2000. On the performance of technology-sourcing partnerships: the interaction between partner interdependence and technology attributes. Academy of Management Journal 43, 1045–1067.

Stuart, T.E., 2000. Interorganizational alliances and the performance of firms: a study of growth and innovation rates in a high-technology industry. Strategic Management Journal 21, 791–811.

Stuart, T.E., Podolny, J.M., 1996. Local search and the evolution of technological capabilities. Strategic Management Journal 17, 21–38.

Teece, D.J., 1982. Towards an economic theory of the multiproduct firm. Journal of Economic Behavior and Organization 3, 39–63.

Teece, D.J., 1992. Competition, cooperation, and innovation: organizational arrangements for regimes of rapid technological progress. Journal of Economic Behavior and Organization 18, 1–25.

Verspagen, B., Duysters, G., 2004. The small worlds of strategic technology alliances. Technovation 24, 563–571.

Zahra, S.A., Ireland, R.D., Hitt, M.A., 2000. International expansion by new venture firms: international diversity, mode of market entry, technological learning, and performance. Academy of Management Journal 43, 925–950.

Zander, U., Kogut, B., 1995. Knowledge and the speed of the transfer and imitation of organizational capabilities: an empirical test. Organization Science 6, 76–92.

Zucker, L.G., 1986. Production of trust: Institutional sources of economic structure. In: Staw, B.M., Cummings, L.L. (Eds.), Research in Organizational Behavior, Vol. 8. JAI, Greenwich.

Zucker, L.G., Darby, M.R., Brewer, M.B., Peng, Y., 1996. Collaboration structure and information dilemmas in biotechnology: organizational boundaries as trust production. In: Kramer, R.M., Tyler, T.R. (Eds.), Trust in Organizations. Sage, Thousand Oaks, CA, pp. 90–113.

Changsu Kim is an assistant professor of strategy and international business at Ewha Womans University, Korea. He earned his Ph.D. at Rutgers University, Newark. His research interests include cross-border alliances, learning and innovation, and FDI from emerging markets.

Jaeyong Song is a faculty of strategy and international business at Seoul National University. Jaeyong Song was a professor at Columbia University and Yonsei University. He received his Ph.D. at the Wharton School. He won both the Barry M. Richman Best Dissertation Award of the Academy of Management and the Gunnar Hedlund Best Dissertation Award from the European International Business Association. His research has appeared in major international journals such as the Management Science, Strategic Management Journal, Organization Science, Journal of International Business Studies, Journal of Economics and Management Strategy, and Journal of Management. He also received research grants from the World Bank, the Asia Development Bank Research Institute, the Long-term Credit Bank Research Institute (Japan), and others.