Learning to Collaborate for Technology Development: Longitudinal Evidence for Patenting Firms in Denmark

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Abstract

Gaining access to essential and valuable resources and technologies not owned by the firm itself has frequently been characterized as a fundamental reason behind strategic technology alliances and research partnerships. In this respect, knowledge leakage is one of the most important concerns. Hence in this paper, we analyze how firms may learn to collaborate in technology development over time. We argue that collaborative experience with domestic and international research partnerships creates knowledge repositories on how to collaborate. We suggest that due to path-dependence and lock-in effects international (domestic) collaborative experience only facilitates the respective type of research partnership. However, knowledge repositories may actually interact, either with each other or with the absorptive capacity of the firm, to become transferable. Based on patent application data of Danish firms at the European Patent Office in the period from 1978 to 2002 we largely find support for our hypotheses. High absorptive capacity, however, decreases the effect that international (domestic) collaborative experience will have on the choice for subsequent international (domestic) research partnerships.

Keywords: Research partnerships, patents, internationalization, path-dependence, Denmark

JEL classification: O33, O34, C23

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1 Introduction

Accessing essential and valuable resources not owned by the firm itself has frequently been characterized as a fundamental reason behind strategic technology alliances and research partnerships (e.g., Teece, 1992b; Hagedoorn et al., 2000; Grant and Baden-Fuller, 2004). In pursuit of a shared R&D objective, such innovation-based relationships involve, at least partly, a significant effort in R&D and serve as an instrument to pool resources and to fill resource gaps in technology development (Hagedoorn et al., 2000). One expectation is that the larger the pool of R&D resources, the greater the number of potential resource combinations which may increase chances for developing technological innovation (Henderson and Cockburn, 1996; Zahra, 1996). Compared to other options to access resources like firm acquisitions (e.g., Capron et al., 1998; King et al., 2008), research partnerships are flexible and permit sharing costs and risks among the partners. The downsides, however, include difficulties in management as a result of joint decision making and control, incompatible goals, opportunistic behavior, and – perhaps most importantly in the context of research partnerships – knowledge leakage (Cassiman and Veugelers, 2002; Li et al., 2008). Avoiding such a loss of knowledge and misappropriation of investments into R&D will be even more challenging when firms choose to collaborate with international partners. However, international partners also promise to bring in valuable resources not available in a firm's home country.

As a result, existing research has largely focused on how to establish a secure governance structure to protect valuable resources from appropriation by opportunistic partners (e.g., Pisano, 1989; Oxley, 1999), on how to reduce the scope of partnerships in an effort to limit points of contact (e.g., Oxley and Sampson, 2004), or how to select suitable partners (e.g., Brouthers et al., 1995; Ireland et al., 2002; Li et al., 2008). Dyer and Singh (1998) have argued that prior ties create trust which is why familiar partners are preferred over new partners. However, Li et al. (2008) distinguish between strangers, acquaintances and friends with respect to the number of prior relationships and find that friends are not always preferred over acquaintances and strangers. In fact, prior ties decrease information asymmetries between the partners which will in turn increase the risk of opportunistic behavior by one partner firm. Hence, a high risk of knowledge leakage could lead firms to prefer a new partner.

While these strands of research emphasize the relationship between a particular pair of firms, relatively little is known about how collaborative experience with one partner may be used to facilitate collaboration with another partner. As Mayer and Argyres (2004: 391) point out, "there has been relatively little analysis of whether and how firms learn to manage their interfirm relationships." Mayer and Argyres (2004) suggest that contracts as they may be used in research partnerships serve as knowledge repositories from which firms may draw in subsequent collaborations. It is however not clear if and under what conditions such knowledge repositories may be generalized into some form of collaboration capability, making subsequent collaborations with new partners more likely. In fact, as the institutional and geographical loci of new technology can be diverse there is a high probability that at least from time to time firms need to engage into relationships with new partners (Teece, 1986, 1992a). While new partners generally involve uncertainty, the level of uncertainty is even higher in case of international collaborations (Reuer and Tong, 2005). Moreover, firms seeking international instead of domestic collaboration need to adapt to the foreign context, regulations, and culture (Tong et al., 2008). It is thus questionable whether knowledge repositories from domestic research partnerships may be extended towards international research partnerships and vice-versa.

Hence in this paper we wish to explore how knowledge repositories are used by firms over time to facilitate subsequent collaboration in domestic or international research partnerships, or to keep technology development internally. Our focus is not on partner-specific knowledge in a contractual relationship but on the stock of knowledge gained either through domestic or international research partnerships. Moreover, studies on contracting in collaborative relationships have mainly used cross-sectional rather than longitudinal data (e.g., Anand and Khanna, 2000) which makes it difficult to detect the effects from knowledge repositories acquired over time. The scarce empirical evidence on learning to collaborate over time is also rather qualitative in nature (Mayer and Argyres, 2004). We use patent application data of the European Patent Office (EPO) from 1978 to 2002 with at least one applicant from Denmark to construct comprehensive measures of learning in research partnerships. Research partnerships are identified as co-applications by a Danish firm and at least one other Danish firm (domestic partnership) or one non-Danish firm (international partnership). Based on more than 8,000 research partnerships and internal technology developments of all patenting firms in Denmark, we estimate multinomial logit models to explain a firm's choice for a particular type of research partnership.

We find that there is considerable path-dependence in the collaborative behavior of firms, i.e. knowledge repositories created through domestic (international) research partnerships only increase the likelihood to collaborate domestically (internationally). This may give rise to lock-in effects in new technology search. Second, our results indicate strong substitute effects between a firms' absorptive capacity and its collaborative experience of either type. In this respect, high absorptive capacity actually reduces the impact of collaborative experience on the choice for either type of research partnership. Third, we document that learning from domestic and international research partnerships complements each other. This suggests that knowledge repositories on how to collaborate can actually be transferred, increasing the propensity that firms will opt for collaborative technology development of either type.

Our paper proceeds as follows. The following section will outline our theoretical background and establish at set of hypotheses. Data, measures and the empirical model are described in section 3 while section 4 will present the results. They are discussed in section 5, leading to conclusions, limitations, and implications for further research in section 6.

2 Theory development

2.1 Benefits and risks of prior research partnership

Research partnerships have typically been distinguished into two types: equity joint ventures with a focus on R&D and research collaborations which are based on contractual agreements (Hagedoorn et al., 2000). In the more economics oriented literature, the latter are also referred to as research joint ventures (RJV) which may create confusion when compared with equity joint ventures. However, the distinction between equity and contract based research joint ventures is not central to our research which is why in the following we will interchangeably refer to research partnerships or research joint ventures.

Research partnerships serve as a way to access critical resources and to fill resource gaps (Das and Teng, 2000). Adopting a resource-dependence perspective, such partnerships are formed to address a firm's dependence on resources owned by others (Pfeffer and Salancik, 1978). In fact, the need for certain resources has frequently been shown to be a central motivation for engaging in research partnerships (e.g., Eisenhardt and Schoonhoven, 1996; Ahuja, 2000). Particularly entrepreneurial firms typically face considerable resource constraints which research partnerships are supposed to mitigate (Brush and Chaganti, 1997; Teng, 2007). RJVs, however, also face a considerable amount of uncertainty, regardless of whether they are domestic or international. That uncertainty typically results from factor- and product-market conditions or the pace of technology evolution, and it is likely that uncertainty increases in an international context where partners originate from different countries, legal frameworks and cultural backgrounds (Tong et al., 2008). One expectation is that trust might be lower between geographically more distant or socially dissimilar partners (Barkema and Vermeulen, 1997). Moreover, international partners may require learning new "rules of the game" in a host country in order to overcome liabilities of foreignness and newness or legitimacy deficits (Zaheer and Mosakowski, 1997). Different legal frameworks may also involve uncertainty about the appropriability conditions of investments into R&D, as well as political risks (Peng, 2003).

The alliance literature, however, suggests that uncertainties can actually be reduced to the extent that firms have established prior ties with a partner (Dyer and Singh, 1998; Gulati and Singh, 1998). Prior partners will also encounter less problems in the transfer of knowledge because causal ambiguities may be reduced, facilitating the flow of knowledge between the partners (e.g., Cohen and Levinthal, 1990; Kogut and Zander, 1992). Moreover, Hoetker (2005) notes that established ties gain importance relative to technological capabilities of the partners when technological uncertainties increase. In this respect, information asymmetries can be reduced and trust can be built up. Trust is typically assumed to reduce transaction costs and uncertainties between the partners, supporting a more productive interaction for example in terms of larger monetary contracts (Hitt et al., 2006). In research partnerships, trust can therefore serve to prevent knowledge leakage and opportunistic behavior but instead facilitate the exchange of knowledge so that both partners benefit (Li et al., 2008).

The downsides of prior research partnerships include path-dependence and lock-in effects (Gulati, 1995). Firms might become less inclined to search for innovation impulses outside of their established network of partnerships, ignoring resource pools that may be available elsewhere. Being reluctant to depart from existing partnerships also decreases the likelihood that radical innovations emerge as novelty can be characterized as a critical factor for radical innovations (Dewar and Dutton, 1986). Multiple interactions, however, might have led to a common mindset of the partners which presumably hinders novelty. New partners may in this respect bring in new information not available from familiar partners. Finally, while trust reduces information asymmetry between partners, firms also expose themselves in that they grant each other access to and knowledge about firm specific operating routines and know-how (Li et al., 2008). As a consequence, they are in a position to appropriate intellectual property not protected by legal instruments like a patent. New partners, by contrast, could in such a situation be hindered from appropriation by using informal methods like lead time, learning curves, or complexity of design. Critical firm resources might therefore be more easily appropriated by a partner firm with prior ties than one without such ties (Li et al., 2008). As a result, literature provides mixed indications concerning the choice of partners in research partnerships. The following section will further delineate our theoretical reasoning by integrating the element of organizational learning, an effort that is the focus of our current research.

2.2 Learning to collaborate

Although contractual arrangements as for example in research partnerships have frequently been analyzed using resource-based theory (Wernerfelt, 1984; Barney, 1991), transaction cost economics (Williamson, 1979) or a combination of both (Mayer and Salomon, 2006), little is known how prior ties may actually enable firms to learn to contract per se, and how learning affects a firm’s choice of partners in RJVs. There is, however, a large body of literature that suggests that learning tends to be a gradual and incremental phenomenon that takes time (e.g., Argote, 1999; Mayer and Argyres, 2004) and that results from repeating organizational routines. Moreover, learning has been shown to be local in that it typically takes place in familiar areas where firms have already acquired some knowledge or experience (Nelson and Winter, 1982; Cohen and Levinthal, 1990; Helfat, 1994). Consequently, firms may actually learn to collaborate over time (Doz, 1996; Anand and Khanna, 2000). Knowledge on the collaboration itself might be retained and used in later transactions to structure and manage other collaborations. In this respect, learning to contract, for example in a research partnership, is an important aspect of learning to collaborate in a more general sense (Mayer and Argyres, 2004).

As a consequence, learning through experience may occur in a number of ways. Firms may better foresee the contingencies associated with research partnerships they were previously unaware of. They should also be in a better position to evaluate the likely consequences of these contingencies on firm performance. Contracts based on experience should therefore be more appropriate to deal with contingencies and protect valuable resources. Hence, learning is connected to contingencies that firms have to cope with over time (Cyert and March, 1992). The fruits of previous learning are gradually embodied in routines upon which firms repeatedly act. In this respect, Mayer and Argyres (2004) argue that contracts serve as knowledge repositories. They accumulate knowledge on how to efficiently organize transactions and collaborate in technology development. However, while Mayer and Argyres (2004) and Li et al. (2008) focus on partner-specific collaborations through which the involved partners gradually learn more about each other, we argue that the repositories of knowledge can actually serve to facilitate collaboration with other, unfamiliar partners as long as the accumulated knowledge on how to collaborate is actually transferable.

There are several conditions that determine to what extent knowledge repositories are transferable. Firms will typically choose between domestic and international research partnerships. Tong et al. (2008) have argued that international research partnerships involve much higher uncertainty that might result from unknown factor- and product market conditions. Moreover, international partnerships entail different regulatory frameworks as well as cultural backgrounds. One expectation is therefore that knowledge repositories on how to collaborate in a domestic context do not serve as instruments to facilitate collaboration in an international context and vice versa, as they do not have any specific value that could be exploited in such a situation. Moreover, in order to find and attract an international research partner, firms need to overcome liabilities of foreignness and newness or legitimacy deficits (Zaheer and Mosakowski, 1997). If knowledge repositories cannot be used to signal the firm's attractiveness to a potential partner its choices will be constrained. Put differently, knowledge repositories based on experiences with well-established either domestic or international partners may serve as signals to other potential domestic or international partners (Rao et al., 2008). In sum, as firms learn through the repeated practice of routines, they will at the same time restrain the range of new learning. Hence, our first hypothesis reads:

Hypothesis 1a (H1a): *Knowledge repositories based on domestic research partnerships will increase the likelihood that firms will enter into research partnerships with domestic partners.*

Hypothesis 1b (H1b): *Knowledge repositories based on international research partnerships will increase the likelihood that firms will enter into research partnerships with international partners.*

While our first hypothesis basically argues that research partnerships create path-dependence and lock-in effects that limit the transferability of knowledge repositories, there is little evidence available whether and how knowledge repositories might interact to complement or substitute each other. In our setup, there are three potential interactions between a firm's knowledge repositories. Knowledge repositories based on domestic or international research partnerships may interact with a firm's internally created knowledge through in-house R&D, as well as with each other. In the following, we will elaborate several arguments on how these three types of interactions may influence the likelihood to enter into research partnerships with domestic or international partners.

Cohen and Levinthal (1990) have argued that in-house R&D not only creates new knowledge but also increases the absorptive capacity of the firm. In this respect, internal and external knowledge have been shown to complement each other which propels the innovation performance of the firm (Cassiman and Veugelers, 2002, 2006). We argue that successful recombination of internal and external knowledge resources may therefore actually increase the transferability of knowledge repositories based on domestic or international research partnerships. First of all, absorptive capacity reduces uncertainties about technologies and the technological competence of potential partners. Moreover, firms might be better able to signal their own competence and attract new partners either domestically or internationally through their in-house R&D. Hence, firms may use both domestic and international research partnerships in combination with their own R&D to facilitate collaboration with new partners. The increased transferability of either knowledge repository should therefore impact the choice for both domestic and international research partnerships. This leads to our second and third hypothesis:

Hypothesis 2a (H2a): *The larger a firm's absorptive capacity, the stronger will be the effect of experience with domestic research partnerships on the firm's choice for a domestic research partnership.*

Hypothesis 2b (H2b): *The larger a firm's absorptive capacity, the stronger will be the effect of experience with domestic research partnerships on the firm's choice for an international research partnership.*

Hypothesis 3a (H3a): *The larger a firm's absorptive capacity, the stronger will be the effect of experience with international research partnerships on the firm's choice for a domestic research partnership.*

Hypothesis 3b (H3b): *The larger a firm's absorptive capacity, the stronger will be the effect of experience with international research partnerships on the firm's choice for an international research partnership.*

In a similar way, knowledge repositories based on experience with domestic and international research partnerships may interact and provide firms with super-additive effects in that they learn to cope with a highly increased number of contingencies that might arise. As a consequence, operating routines become more flexible, reducing path-dependence and lock-in effects. Hence, our fourth hypothesis can be stated as:

Hypothesis 4a (H4a): *The larger a firm's experience with domestic research partnerships, the stronger will be the effect of a firm's experience with international research partnerships on the firm's choice for a domestic research partnership.*

Hypothesis 4b (H4b): *The larger a firm's experience with domestic research partnerships, the stronger will be the effect of a firm's experience with international research partnerships on the firm's choice for an international research partnership.*

3 Methods

3.1 Data

We use data on the patenting activity of all Danish firms at the European Patent Office (EPO) to qualify new technology development as being carried out in-house or collaboratively. For this purpose, we include on all patent applications at the EPO that were filed between 1978 and 2002 by at least one applicant with Danish residency. Patent applications are used rather than patent grants because the average grant time at the EPO of four to five years (Kaiser and Schneider, 2005) implies that a substantial number of patents recently applied for during the time period considered for estimation would be lost if patent grants were used instead. Moreover, no matter whether or not the application was eventually granted, the patent application itself can be regarded as an indicator for whether a research partnership did occur or not.

The "time stamp" of the patent applications is the "priority date", the date at which the invention was first filed for patent protection at the EPO or any national patent office. The EPO data consist of 11,784 patent applications in total by 2,627 unique non-private Danish applicants over the period from 1978 to 2002. The EPO data do not come with a unique firm identifying number of the kind needed to combine it with additional data. Hence, we, mostly manually attached our EPO data to Statistics Denmark's firm identifiers in order to merge it with balance sheet data from Købmandsstandens Oplysningsbureau (KOB). Inclusion of the balance sheet data, however, reduces our sample size by 28 percent. What is even more important is that the number of international research partnerships drops by 35 percent (to 181) and the number of domestic research partnerships by as much as 80 percent (to 29). This reduces the statistical significance of our parameter estimates for the model that includes the balance sheet data substantially. Since there is *qualitative* difference between the two sets of estimation results, our discussion focuses on the set of results from the full data, the "EPO only" data. Estimation results for the data set that does include the balance sheet data are available from the authors upon request.

Our empirical analysis excludes "private inventors", i.e. individuals unrelated to firms or public research institutions and who appear as the sole applicant and the sole inventor on the patent application. We exclude private inventors since the theory underlying our hypotheses is concerned with firms.[2]

[2] Our research is focused on firms and not on universities or other research institutes which is why they should be removed from our data. However, our data stems from a time period where the equivalent to the US Bayh-Dole-Act has not yet come into force in Denmark. Hence, virtually all patents that might have been developed at universities would show a university scientist (i.e. a "private inventor") as the applicant and thus do not show up in our sample.

3.2 Measures

Dependent variable

Our dependent variable, the choice a firm makes for a specific type of research partnership leading to a patent application, is derived from the patent data. These data contain information on the identity of the patent applicants, including their country of origin. A domestic research partnership is defined as a patent application that lists at least two unaffiliated Danish firms as the applicants of the patent. An international research partnership is defined as a patent application that lists at least one Danish and one foreign firm as the applicants of the patent. Consequently, patents with more than one Danish applicant and at least one foreign firm, i.e. mixed cases, are perceived as an international research partnership. A non-collaborative patent application, i.e. technology fully developed internally by a Danish firm, constitutes our base outcome.[3]

Explanatory variables

Knowledge repositories. We capture knowledge repositories based on domestic or international research partnerships through prior experience with these two modes of collaboration for technology development. Experience can accumulate through prior co-patenting. We therefore take the stock of patents a firm has applied for since 1978 collaboratively either with domestic or international partners as our measures for knowledge repositories. The patent stock is calculated as follows:

$$S_{it} = P_{it} + (1-\delta)S_{it-1} \qquad (1)$$

where i denotes firm i and t denotes time t. We discount past patent applications by discount factor δ which we set to .3 to be consistent with other studies (e.g., Blundell et al., 1995). Our results remain robust to alternative discount factors.

Absorptive capacity. Cohen and Levinthal (1990) have argued that absorptive capacity is developed as a by-product of a firm's in-house R&D activities. It is developed over time and refers to an accumulation of knowledge. As a consequence, we measure absorptive capacity as the total patent stock of the firm following equation (1), regardless of whether a patent was developed internally or collaboratively.

Control variables

We also control for a set of additional variables that are likely to affect the choice for a particular type of research partnership. These variables relate to (i) revealed technological advantages of the firm and Denmark as a country in general, (ii) technological specialization,

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3 It is important, however, to distinguish between internal and external collaboration since many Danish firms patent jointly with their domestic or foreign subsidiaries. Lego A/S, a toymaker, and Novo Nordisk A/S, a pharmaceutical firm, for example always co-patent with their Swiss (Lego A/S) and U.S. (Novo Nordisk A/S) subsidiaries. We checked all patent applications whether the applicants might be affiliated with each other using the ownership information in the KOB data. For those patents where that information was unavailable we manually checked the applications for affiliation. All patents that turned out to be filed by multiple but affiliated applications were coded as non-collaborative.

(iii) domestic technology supply and (iv) a set of "standard" control variables including firm age, year and technology sector dummies.

Revealed national technological advantage. Differences in national innovation systems have been referred to as reasons for international R&D collaborations as firms seek immobile assets which are location-specific (Narula and Duysters, 2004). The theory of national innovation systems highlights the issue of path-dependence and stickiness of innovation capabilities within countries (Lundvall, 1992). Research partnerships may therefore be seen as a way by which firms may tap into location-specific competences in different innovation systems and hence to avoid being locked in a single national innovation system. We follow Le Bas and Sierra (2002) to calculate the revealed technological advantage (RTA) of Denmark in technology class *j* as:

$$RTA_{jt}^{DK} = \frac{P_{jt}^{DK} / \sum_{i} P_{jt}^{DK}}{\sum_{j} P_{jt} / \sum_{i}\sum_{j} P_{jt}} \qquad (2)$$

where P_{jt}^{DK} denotes the number of Danish patent applications in technology class *j* and P_{jt} denotes the total number of patent applications per year at the EPO. We merge this variable to each firm on its main technology sector and year. We define a firms' main technology area as the technology area in which it applied for most of its patents. If firms have an equal number of patents in certain technology classes, we randomly assign its main technology area. In order to calculate the RTAs, we use the OST-INPI/FhG-ISI classification of patents which is based on the International Patent Classification system (IPC) to allocate each patent application into one of 30 mutually exclusive technology groups (see OECD, 1994: 77-78, for the definition).[4] The data for the total number of patents in technology class *j* are taken from patent records at the EPO. Our RTA_{jt}^{DK} variable varies across technology sectors and time. It does not vary across firms unless firms are from different technology sectors. Larger values of RTA_{jt}^{DK} indicate greater technological strength. We hence expect the effect of RTA_{jt}^{DK} to be negative for the choice of international research partnerships.

Revealed firm-specific technological advantage. Firms that are technologically weak may be more reluctant to seek research partnerships than technologically strong ones. Cantwell and Kosmopoulou (2000) for example analyze the determinants of internationalization of R&D based on patent data from the US Patent Office (USPTO) for 792 of the world's largest industrial firms in the period from 1965 to 1995. They find that the degree of internationalization of R&D depends on the technological advantage of firms rather than the R&D intensity of industries and firms as suggested by Patel and Pavitt (1997). If technologically strong, firms, regardless of the R&D intensity of the industry, tend to be highly internationalized and the opposite seems to hold if firms are technologically weak, i.e. that R&D internationalization tend to be modest. We hence expect the effect of the firm-specific RTA, RTA_{it}, to be positive for the choice of international research partnerships.

4 For an overview see Table 4 in the Appendix.

We calculate the firm-specific RTA as the patent stock of each firm in its main technology area, S_{it}^{j}, relative to the total number of EPO patents in a firms' main technology area P_t^h, in relation to the ratio of a firms' discounted stock of patents, S_{it}, and the total number of EPO patent applications per year, P_t :

$$RTA_{it} = \frac{S_{it}^{j} / P_t^{j}}{S_{it} / P_t} \qquad (3)$$

We use the stock rather than the flow since the stock is a representation of a firm's entire patent history while the number of patent applications per year is just a snapshot. We relate the stock of patents to the flow of patents within each technology class since the flow of patents represents the presently available expertise in the respective area – which is what asset augmenting firms seek. It turns out that our firm-level RTA is quite skewed to the right which is why we use its natural logarithm instead of its level in the empirical analysis.

Technological specialization. It seems likely that a highly specialized firm may find it difficult to find domestic collaboration partners given the size of Denmark. At the same time, however, specialized firms may be regarded as attractive partners in a research partnership, in particular if they offer (specialized) complementary knowledge. The effect on the choice for a research partnership is therefore less clear. We calculate technological specialization using a Herfindahl-Hirschman Index to depict concentration of the firm's patents in a particular technology area.

Domestic technology supply. We expect that firms are less likely to cooperate with foreign firms if the domestic technology base is strong. We therefore generate a variable that measures the discounted stock of Danish patent application in technology class *j*. We attach this variable to each firm based on its main technology class.

Firm age. We measure firm age as the respective current year minus the first year of patent application. Unfortunately, as the merge of balance sheet data turned out not to be viable, we cannot use actual firm age. Based on the merged dataset, using actual age instead of "patenting age" does not affect our estimation results qualitatively or quantitatively. Narula and Duysters (2004) discuss the role of multinational experience for firms choosing between collaborative ventures and equity based linkages when going abroad. They argue that international research partnerships may be a first best option to equity-based linkages if firms use alliances to get access to technology across borders because multinational experience may expand the exploration potential. On the other hand international R&D cooperation may also be seen as a second-best option used by firms as a market entry tool to reduce uncertainty. As collaborative ventures involve organizational costs in terms of shirking and conflicts of interest, hierarchical control will be preferred to international research partnerships as firms get more international experience. Therefore the effect of experience on the probability of international R&D cooperation is expected to be ambiguous. Experience in domestic R&D cooperation is expected to have a positive influence on the probability of domestic R&D cooperation since more experienced firms may have more developed networks than younger firms and may also have developed higher absorptive capacity.

Technology class and year dummies. We include six technology class dummies that constitute an aggregation of the OST-INPI/FhG-ISI list and a set of year dummies.

We lag the patent stock variables, the technological strength variables, the technological specialization variables, the technology supply variable and firm size by one year in order to prevent spurious contemporaneous correlations. All other variables enter with their contemporary values.

3.3 Econometric model

We use a multinomial logit model to estimate the probability of cooperation choice conditional on our set of explanatory variables. Our dependent variable is unordered and categorical which makes the multinomial logit model the appropriate tool. Just like the popular binomial logit model, a model for two choices only, the multinomial logit model requires one choice to be the "base" choice and all coefficient estimates are to be interpreted relative to this base choice. We determine the internal technology development mode to be the base choice since it is the by far most populated one. The coefficient estimates of the multinomial logit model do not directly translate into marginal effects as it is the case for OLS regressions. Our focus is, however, on the qualitative effects. We therefore report our estimation results in terms of coefficient estimates.

We estimate two model specifications. In order to analyze the differential effects of the experience with each mode of research partnerships, we include the total stock of patents, the stock of international collaborative patents, and the stock of domestic collaborative patents. Moreover, in the second specification we allow for complementarities between the collaboration modes by using interacting terms. Specifically, we interact the total patent stock with the stock of international collaborative patents as well as with the stock of domestic collaborative patents. Moreover, we interact the stock of international collaborative patents with the stock of domestic collaborative patents.

4 Results

Table 1 shows the descriptive statistics. It turns out that Danish firms patenting at the EPO dispose on average over a discounted patent stock of 25 patents. Only a small fraction of these patents has been filed with domestic partners, while on average roughly six patents result from international research partnerships. Table 3 in the Appendix reports the bivariate correlations. Despite the rather high correlation between the three patent stocks, the variance inflation factor (VIF) provides no indication for multicollinearity (Belsley et al., 1980).

Table 1: Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Total patent stock	7873	25.423	46.695	0	174.730
Stock of domestic collaborative patents	7873	0.139	0.670	0	15.400
Stock of international collaborative patents	7873	5.716	10.240	0	42.339
Domestic technology supply (in logs)	7873	7.137	2.152	0	10.289
Firm-specific RTA	7873	2.807	1.019	0	7.599
RTA of Denmark	7873	1.797	1.224	0	6.170
Technological specialization	7873	0.533	0.295	0.128	1
Patenting age (years)	7873	12.020	6.211	1	25
Electrics (d)	7873	0.077	0.267	0	1
Process technology (d)	7873	0.092	0.289	0	1
Instruments (d)	7873	0.109	0.311	0	1
Mechanics (d)	7873	0.135	0.342	0	1
Other (d)	7873	0.114	0.317	0	1

(d) denotes dummy variable

Table 2 shows the results of the two specifications of the multinomial logit model to explain a firm's choice for a domestic and an international research partnership (r.p.).[5]

[5] As a consistency check, we estimated the models using the merged EPO/balance sheet dataset which additionally includes firm industry dummies and firm size in terms of the number of employees, as well as firm age instead of patenting age. The signs of the variables of interest do not differ between the two datasets. What differs, however, is the statistical significance with which the coefficients related to the choice for a collaboration mode are estimated. Results are available from the authors upon request.

Table 2: Results of the multinomial logit models

	Model 1		Model 2	
	International r.p.	**Domestic r.p.**	**International r.p.**	**Domestic r.p.**
Total patent stock	-0.002	-0.038	0.000	-0.096
	(0.003)	(0.026)	(0.004)	(0.076)
Stock of domestic collaborative patents	0.021	0.367***	-0.269	3.323***
	(0.061)	(0.070)	(0.318)	(0.363)
Stock of international collaborative patents	0.052***	-0.024	0.043***	-0.161***
	(0.010)	(0.024)	(0.016)	(0.050)
Interaction (total patent stock*domestic coll.)			-0.046***	-0.815***
			(0.009)	(0.152)
Interaction (total patent stock*international coll.)			-0.000**	0.005
			(0.000)	(0.003)
Interaction (domestic coll.*international coll.)			0.403***	1.076***
			(0.071)	(0.211)
Domestic technology supply (in logs)	-0.173**	-0.117*	-0.133*	-0.113*
	(0.071)	(0.065)	(0.075)	(0.069)
Firm-specific RTA	0.021	-0.278***	-0.010	-0.180**
	(0.077)	(0.072)	(0.085)	(0.074)
RTA of Denmark	0.025	0.100	0.182***	-0.024
	(0.075)	(0.089)	(0.070)	(0.102)
Technological specialization	-0.448	1.332***	-0.504*	1.657***
	(0.295)	(0.301)	(0.301)	(0.337)
Patenting age (years)	-0.056***	-0.107***	-0.065***	-0.107***
	(0.014)	(0.018)	(0.016)	(0.018)
Electrics (d)	-1.186***	-0.784***	-0.794**	-0.795**
	(0.328)	(0.287)	(0.336)	(0.316)
Process technology (d)	-1.222***	-0.578**	-1.160***	-0.435
	(0.358)	(0.257)	(0.367)	(0.268)
Instruments (d)	-0.539**	-1.211***	-0.361	-1.060***
	(0.267)	(0.276)	(0.270)	(0.280)
Mechanics (d)	-1.399***	-1.228***	-1.216***	-1.200***
	(0.297)	(0.293)	(0.303)	(0.304)
Other (d)	-1.418***	-1.279***	-1.272***	-1.015***
	(0.326)	(0.299)	(0.337)	(0.300)
Year dummies	Yes	Yes	Yes	Yes
Constant	-2.326***	-1.934***	-2.586***	-2.625***
	(0.698)	(0.509)	(0.723)	(0.523)
N	7873		7873	
Wald chi²(65; 71)	498.06		634.69	
Prob > chi²	0.000		0.000	
Pseudo R^2	0.128		0.174	

(d): dummy variable; standard errors in parentheses.
*,**,*** indicate statistical significance at the 10%, 5% and 1% level
Internal technology development (i.e. non-collaborative patent) is the base outcome.
Chemicals is the reference technology area.

A first striking result from Model 1 is that experience with international (domestic) research partnerships increases the likelihood that firms will choose an international (domestic) partnership for their next technology development project. Our results suggest that there are considerable path-dependence and lock-in effects. The effects from absorptive capacity in terms of the total patent stock of the firm are for both choices not significant. Moreover, experience with international research partnerships does not affect the choice for a domestic research partnership and vice versa. Hence, we cannot reject H1a and H1b.

Turning to Model 2 the results from Model 1 remain stable. Experience with international (domestic) research partnerships increases the likelihood of an equivalent choice of partnership mode. However, we also find a significant negative effect of experience with international research partnerships on the choice for a domestic research partnership. This finding even substantiates the indication of path-dependency and lock-in effects.

Apart from the linear effects, Model 2 contains the interaction effects between the firm's absorptive capacity and the knowledge repositories based on international and domestic research partnerships. For both choices, international and domestic research partnerships, there is a negative and significant interaction between absorptive capacity and experience with domestic research partnerships. Apparently, both do not complement but instead substitute each other. In other words, absorptive capacity does not increase the effect that experience with domestic research partnerships has on the choice for an international or domestic research partnership. Instead, our results suggest that firm revert to internal, i.e. non-collaborative, technology development. Consequently, H2a and H2b have to be rejected.

Regarding the interaction between absorptive capacity and experience with international research partnerships we find a similar substitute relationship with the choice for an international research partnership. The effect is insignificant for domestic research partnerships. As a result, H3a and H3b have to be rejected.

Contrary to these findings of substitutive effects, we find strong positive complementarity between the experience with international and domestic research partnerships for the choice of either an international or domestic research partnership. Experience with both types of research partnerships apparently seems to provide super-additive effects, increasing the likelihood to engage in both types of research partnerships. H4a and H4b therefore receive support.

Regarding the control variables, it turns out that the firm-specific revealed technological advantage does not affect the choice for an international research partnership but negatively affects the choice for a domestic research partnership. Hence, technologically strong firms do not increase their collaborative behavior but instead reduce domestic research partnerships. This finding may be result of knowledge leakage concerns that the firm may have when collaborating with domestic partners. The revealed technological advantage for Denmark has a positive and significant effect on the choice for an international research partnership, but it is insignificant for domestic research partnerships. We expected the effect for international research partnerships to be negative because Danish firms might be more reluctant to collaborate internationally when technological competence in a certain area in Denmark is high. The effects of technological specialization differ between the two choices: the effect is negative for international research partnerships and positive for domestic research partnerships. Highly specialized firms therefore seem to prefer domestic over international partners, despite the relative low number of collaborative opportunities given the size of Denmark. But highly specialized firms may also be much more reliant on a close network of partners from the outset, and that network may be easier to establish domestically. Regarding the domestic technology supply we find negative effects for the choice of both domestic and international research partnerships which at least partly confirms our reasoning that Danish firms will be less likely to collaborate internationally if the domestic technology base is strong. Finally, there are strong negative effects of the patenting age on engaging into collaborative ventures. It seems that younger firms are particularly inclined to collaborate, suggesting that they are more resource-constraint and thus in greater need to bridge resource gaps for which research partnerships provide a platform.

5 Discussion

Our research set out to explore the effects of learning to collaborate in technology development through the accumulation of experience. Previous literature has made it clear that one of the most critical issues in research partnerships is the threat of knowledge leakage (e.g., Li et al., 2008). We have argued that firms not only be able to cope with that problem through deliberate partner selection but that collaborative experience with more than one partner might itself become valuable as a repository for knowledge on how to collaborate. Knowledge repositories are expected to be built through gradual learning in research partnerships (Mayer and Argyres, 2004). The extent to which they may be used in order to facilitate future collaboration with new partners, however, depends on their transferability. We have drawn a broad distinction between domestic and international research partnerships. International research partnerships involve typically much more uncertainty, different regulatory frameworks to which a firm will have to adapt but also different cultural backgrounds that make coordination more difficult (Tong et al., 2008). In this respect, our empirical findings confirm our hypothesis that firms will encounter substantial difficulties to increase the transferability of their knowledge repositories. We find substantial path-dependency and lock-in effects. Firms that chose international (domestic) research partnerships are very likely to choose the same type of collaboration for subsequent partnerships. Although firms learn through the repeated practice of routines, they will at the same time restrain the range of new learning that would result from new partners in a different institutional context.

Second, our research intended to identify conditions under which knowledge repositories based on either type of research partnerships might be transferable. In this respect, we ascribed a key role to the absorptive capacity of the firm (Cohen and Levinthal, 1990). Internal and external knowledge have frequently been shown to complement each other (Cassiman and Veugelers, 2002, 2006). Therefore, one expectation is that the recombination of such knowledge will increase the transferability of knowledge repositories and lead firms to engage in research partnerships of the type they did not before. However, our empirical findings suggest the contrary. Apparently, absorptive capacity and knowledge repositories substitute each other which actually increases the likelihood that firms will revert to internal technology development. A reason for this may be that firms with strong technological capabilities are highly concerned with potential knowledge leakage and therefore shift to more in-house technology development. After all, this will allow them to exploit their knowledge base more intensively.

Similarly, we have argued that knowledge repositories based on experience with domestic and international research partnerships do interact positively and increase the transferability of collaborative experience. In fact, our empirical results substantiate complementarity between both types of research partnerships. This suggests that firms may learn to cope with a highly increased number of contingencies that might arise in domestic or international research partnerships. Through the interaction of both knowledge repositories, operating routines become more flexible which reduces path-dependence and lock-in effects.

6 Conclusion

While our research extends existing literature in a number of ways, there are also several limitations that we need to acknowledge. First, due to the low number of domestic research partnerships observed it became unfeasible to include more information on firm characteristics as control variables to the collaboration choice. Moreover, based on the patent data we use we cannot distinguish between the type of research partnership, whether it is based on a contract or an equity linkage. Existing research has, however, shown that considerable differences exist between both types of research partnerships in the extent that knowledge leakage might occur (Li et al., 2008). Third, our arguments on the transferability of knowledge repositories only refer to domestic versus international research partnerships. It would be desirable to actually distinguish domestic or international research partners into familiar and new partners. This would allow a more precise analysis to what extent firms actually engage in collaborative ventures with new partners. Besides providing remedies for these issues, future research could focus on the realized value of jointly developed technology compared to internal developments. It could be argued that new partners bring in novel and thus valuable knowledge that can be used in recombination with internal knowledge. Consequently, the value of these patents should be higher than non-collaborative patents.

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Appendix

Table 3: Correlations

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Total patent stock	1.000												
2. Stock of domestic collaborative patents	0.071	1.000											
3. Stock of international collaborative patents	0.816	0.029	1.000										
4. Domestic technology supply (in logs)	0.598	0.038	0.551	1.000									
5. Firm-specific RTA	-0.044	-0.018	-0.053	-0.067	1.000								
6. RTA of Denmark	0.527	-0.002	0.450	0.487	0.294	1.000							
7. Technological specialization	-0.440	-0.042	-0.517	-0.445	0.020	-0.349	1.000						
8. Patenting age (years)	0.437	0.030	0.479	0.497	0.066	0.272	-0.461	1.000					
9. Electrics (d)	-0.150	0.127	-0.155	-0.270	-0.027	-0.273	0.160	-0.158	1.000				
10. Process technology (d)	-0.168	-0.036	-0.164	-0.225	0.094	0.022	0.073	-0.040	-0.092	1.000			
11. Instruments (d)	-0.178	-0.023	-0.180	-0.085	-0.202	-0.190	0.189	-0.084	-0.101	-0.111	1.000		
12. Mechanics (d)	-0.201	-0.052	-0.198	-0.253	-0.036	-0.258	0.042	-0.109	-0.114	-0.126	-0.138	1.000	
13. Other (d)	-0.169	-0.056	-0.180	-0.222	-0.015	-0.126	0.167	0.031	-0.104	-0.114	-0.125	-0.142	1.000
Mean Variance Inflation Factor (VIF): 3.18													

Table 4: Classification of technology areas according to OST-INPI/FhG-ISI

Code	Description Classification
1	Electrical machinery, electrical energy
2	Audiovisual technology
3	Telecommunications
4	Information technology
5	Semiconductors
6	Optics
7	Analysis, measurement, control technology
8	Medical technology
9	Nuclear engineering
10	Organic fine chemistry
11	Macromolecular chemistry, polymers
12	Pharmaceuticals, cosmetics
13	Biotechnology
14	Agriculture, food chemistry
15	Chemical and petrol industry, basic materials chemistry
16	Chemical engineering
17	Surface technology, coating
18	Materials, metallurgy
19	Materials processing, textiles paper
20	Handling, printing
21	Agricultural and food processing, machinery and apparatus
22	Environmental technology
23	Machine tools
24	Engines, pumps and turbines
25	Thermal processes and apparatus
26	Mechanical elements
27	Transport
28	Space technology, weapons
29	Consumer goods and equipments
30	Civil engineering, building, mining