J Evol Econ (2014) 24:399–420
DOI 10.1007/s00191-014-0344-x

REGULAR ARTICLE

Absorptive capacity and innovation: when is it better to cooperate?

Abiodun Egbetokun · Ivan Savin

Published online: 15 February 2014

Abstract Cooperation can benefit and hurt firms at the same time. An important question then is: when is it better to cooperate? And, once the decision to cooperate is made, how can an appropriate partner be selected? In this paper we present a model of inter-firm cooperation driven by cognitive distance, appropriability conditions and external knowledge. Absorptive capacity of firms develops as an outcome of the interaction between absorptive R&D and cognitive distance from voluntary and involuntary knowledge spillovers. Thus, we offer a revision of the original model by Cohen and Levinthal (Econ J 99(397):569–596, 1989), accounting for recent empirical findings and explicitly modeling absorptive capacity within the framework of interactive learning. We apply that to the analysis of firms' cooperation and R&D investment preferences. The results show that cognitive distance and appropriability conditions between a firm and its cooperation partner have an ambiguous effect on the profit generated by the firm. Thus, a firm chooses to cooperate and selects a partner conditional on the investments in absorptive capacity it is willing to make to solve the understandability/novelty trade-off.

Financial support from the German Science Foundation (DFG RTG 1411) is gratefully acknowledged. Thanks are due to very helpful comments and suggestions from Uwe Cantner and Robin Cowan as well as from participants at the SPRU 18th DPhil Day in Brighton, 14th International J. A. Schumpeter Society Conference in Brisbane and 6th Summer Academy on Innovation and Uncertainty in Jena. The usual disclaimers apply.

A. Egbetokun · I. Savin (✉)
Graduate College Economics of Innovative Change, Friedrich Schiller University and Max Planck Institute of Economics, Bachstrasse 18k Room 216, 07743 Jena, Germany
e-mail: ivan.savin@uni-jena.de

I. Savin
Chair for Econometrics and Statistics, Graduate School of Economics and Management, Ural Federal University, Mira 19, 620002 Yekaterinburg, Russian Federation

Keywords Inter-firm cooperation · Absorptive capacity · Cognitive distance · Innovation · Knowledge spillovers

JEL Classification C63 · D83 · L14 · O32 · O33

1 Introduction

This paper presents a new theoretical model of absorptive capacity and cooperation between firms. The aim is not to completely capture the motivations for cooperation; rather, we focus on a very specific effect, that is, knowledge sharing or what (De Bondt 1996) termed the "voluntary exchange of useful technological information". In this sense our model shares the features of Cowan et al. (2007) model of bilateral collaboration where firms form alliances purely based on the production of shared knowledge.

Inter-firm cooperation for learning and innovation has become more common in recent years, mainly due to rapid technological progress and changes in the business environment. Quickly advancing technological knowledge and rising costs of R&D make it virtually impossible for any firm to maintain in-house all the capabilities and knowledge required for production. Moreover, increasing specialisation creates a situation where firms occupy relatively narrow positions in the knowledge space. Consequently, firms often need knowledge[1] that lies outside their core competence. The formation of alliances with other organisations has proven to be an effective way to access external knowledge to complement endogenous capabilities (Powell and Grodal 2005; de Man and Duysters 2005; Brusoni et al. 2001; Bamford and Ernst 2002; Powell 1998).

For such alliances to have the desired effects, firms require absorptive capacity to understand and apply knowledge generated elsewhere. This capacity is developed by investing in R&D (Cohen and Levinthal 1989, henceforth CL).[2] Moreover, the effectiveness of alliances is known to have an inverted 'U'-shaped relation with cognitive distance. In alliance formation, therefore, firms need to balance between their technological heterogeneity and overlap with potential partners (Nooteboom 1999). This creates a proximity trade-off and has been a major focus in the recent literature.[3]

However, other issues are also important. Reciprocal terms of cooperation require a firm to share some of its knowledge with the partner in order to gain access to the

[1] Henceforth, knowledge in this sense includes technologies that firms use in innovation. Innovation refers to a technically new product which develops as an outcome of R&D (see the Oslo Manual, OECD 2005). Consequently, by R&D profit we imply profit due to innovation.

[2] Although recent studies have argued that absorptive capacity, being a multidimensional concept, is not fully proxied by R&D or staff quality alone (Flatten et al. 2011; Zahra and George 2002), we assume that a significant portion of it is embodied in R&D performance. Therefore, our conceptualisation of absorptive capacity in this paper derives mainly from a firm's R&D investments.

[3] Some studies (e.g., Cantner and Meder 2007, Mowery et al 1996) have also shown that cognitive proximity reduces over time. This affects the learning and innovation potential of an alliance and reduces the likelihood that the same partners will cooperate in the next period. This dynamic is important and we address it in a subsequent paper.

latter's knowledge base (Fehr and Gächter 2000). This is like a 'two-edged sword': if the partner can learn faster and is more capable to innovate, a firm then runs the risk of making its partner better at its own expense. For this reason, voluntary spillovers or appropriability conditions between cooperation partners become a very critical factor to consider in cooperation. For the same reason, a firm will take the R&D efforts of its potential partner seriously since that is the main source of absorptive capacity. When these are combined with the challenge of cognitive distance, an important practical question arises: when is it better for a firm to cooperate?

In this paper, we approach the question from a theoretical perspective by looking at the contribution of absorptive capacity (driven by cognitive distance, appropriability conditions and external knowledge) to firms' R&D profit. To do this, we develop a model of inter-firm cooperation in which partners increase their knowledge stock by sharing complementary knowledge. The amount of external knowledge absorbed depends on absorptive capacity, and the new knowledge affects firm performance through innovation-driven profit. For a representative agent, we examine the conditions under which a cooperative strategy is superior to non-cooperation in terms of profit generated.

Two things set our model apart. First, a firm develops absorptive capacity not as a side-effect of total R&D but by devoting a share of its total R&D budget explicitly to it. This creates an investment trade-off. Second, accounting for cognitive distance allows us to distinguish voluntary spillovers within an alliance from other forms of external knowledge. With these elements, we are able to modify the original absorptive capacity model of CL for the context of inter-firm alliances. We use that to study how cooperation affects firm performance in terms of profit. The analyses in the present paper treat cognitive distance as exogenous. This simplification allows us to focus on the specific effect in which we are interested, that is, how the profits of a representative firm evolve with regard to its cooperation strategy. In a follow-up paper (Savin and Egbetokun 2013), we extend our model to analyse the dynamic scenario in which firms' absorptive capacity and their cognitive distance are affected by past decisions.

This study contributes to understanding cooperation and R&D investment preferences of companies and, therefore, has important theoretical and practical applications. The theoretical predictions of our model are more relevant in the context of interactive learning, and our comparative results offer some practical insight on alliance formation decision-making.

2 Literature overview

Technological progress develops along certain trajectories within a given technological paradigm. Each of these trajectories contains some technological opportunities which are either intensive or extensive. In the former case, companies explore opportunities on a particular trajectory by investing in own R&D. In the latter case, firms make use of external knowledge generated by other firms and public research. For this, however, at least a share of the external knowledge must not be a private good (i.e., not appropriated by the owner). The magnitude of this share depends on the effectiveness of the mechanisms by which knowledge is protected - the appropriability conditions (Dosi 1982). In the literature, there is a long discussion on the trade-off between knowledge spillovers and appropriability conditions starting from Arrow (1962). It is argued that spillovers create a negative appropriability incentive. Reducing the innovation rent, large spillover possibilities result in lower (than optimal from a social point of view) level of R&D investments. However, due to the heterogeneity of companies, knowledge transfer via these spillovers contributes to technological progress and can be beneficial for recipient firms (de Fraja 1993). Those spillovers are nevertheless only effective if the recipient of knowledge has a sufficient capacity to absorb it.

Absorptive capacity, that is the ability to value, assimilate and apply new knowledge, was originally conceptualised by CL as a byproduct of a firm's R&D efforts. By allowing the firm to complement its own knowledge with incoming spillovers, this capacity enhances a firm's problem-solving ability (Kim 1998). Zahra and George (2002) extended the concept of absorptive capacity by differentiating between potential and realised absorptive capacity. Potential absorptive capacity involves the acquisition and assimilation of knowledge spillovers, while realised absorptive capacity guarantees the application of this knowledge through the development and refinement of routines that facilitate its transformation and exploitation.

As already hinted, spillovers generally arise from two sources: public and private R&D. Compared to public R&D, spillovers from private R&D are often not easily accessible. Moreover, in the context of today's rapidly changing and highly competitive business environment, spillovers from other firms' R&D sometimes provide more relevant complementary resources. Thus, firms often feel the need to engage in cooperation with other firms to gain access to such knowledge spillovers. In this context, both dimensions of absorptive capacity are at work. Potential absorptive capacity helps the firm to identify an appropriate partner and learn from it, while realised absorptive capacity enables the firm to deploy the knowledge acquired in innovation which enhances profit. Indeed, recent empirical work on inter-firm learning and alliances has shown that firms with higher absorptive capacity tend to benefit more from external knowledge (e.g., de Jong and Freel 2010, Lin et al. 2012).

When a firm engages in cooperation, in addition to involuntary spillovers from other sources it can also appropriate voluntary spillovers from its partners (Gulati 1998). But securing access to voluntary spillovers through partnerships has a potentially negative side effect because of the reciprocity that characterises cooperative arrangements. In exchange for accessing a (potential) partner's knowledge stock, a firm also needs to open up its own knowledge base (Fehr and Gächter 2000). Consequently, spillovers from the firm's R&D efforts do not only reduce its own appropriation, they potentially improve its competitor's R&D performance.[4] This is a 'cost of partnership' which constitutes another form of the negative appropriability incentive. This negative incentive is lowered because the partner firm does not

[4]This argument is important for our model and will be applied later in modeling the firm's profit.

possess perfect absorptive capacity to appropriate all the spillovers (CL, p. 575-6; (Hammerschmidt 2009, p.426)). Thus, what a firm worries about is not necessarily the total spillovers it generates, but how much its partner can absorb, that is, the effective spillovers which increase as the absorptive capacity of this (competing) partner increases.[5] Moreover, the firm also benefits from cooperation because it has access to a pool of knowledge larger than just its own, particularly when the partner holds complementary technological knowledge thereby creating a higher potential to innovate.

The relative value of knowledge spillovers can be represented by the distance between partners.[6] If the distance is small, companies well understand each other and there is much less uncertainty (Lane and Lubatkin 1998), but there might be no new knowledge to learn and, hence, there is the risk of lock-in. In contrast, if the distance is large, the knowledge has higher novelty but is too difficult to absorb and coordination problems may arise (Boschma 2005). This leads to the optimal cognitive distance hypothesis which has been the subject of many studies. The consensus in the empirical literature is that technological or cognitive proximity between cooperation partners has an inverted 'U'-shaped relation with the value of learning the partners obtain (or, alternatively, the innovative potential of the alliance) (Lin et al. 2012; Gilsing et al. 2008; Nooteboom et al. 2007; Wuyts et al. 2005). An understandability–novelty trade-off exists such that effective learning by interaction is better accomplished by limiting cognitive overlap while securing cognitive proximity.[7]

The discussion so far is based on a perception of absorptive capacity as a passive by-product of R&D investments made to generate inventions. However, it can be argued that the allocation of R&D resources is not a simple and unidirectional decision. A distinction can be made between absorptive R&D and inventive R&D. Absorptive R&D refers to the investments made to benefit from knowledge spillovers while inventive R&D is the effort made by a firm to generate original knowledge (Hammerschmidt 2009; Cantner and Pyka 1998). This distinction reflects the difference between "the exploration of new possibilities and the exploitation of old

[5] In our model we are concerned with firms competing on the same technological trajectory. In the extreme case that the cooperating partners operate in different industries, competition between them is mostly negligible. In this case, spillovers do not constitute a disincentive to cooperation and R&D investments (Cantner and Pyka 1998, p. 374).

[6] Distance, in this sense, includes not only cognitive distance but also organisational, social, institutional and geographical ones (Boschma 2005). For instance, Dettmann and von Proff (2010) demonstrated that organisational and institutional proximity facilitate patenting collaboration over large geographical distances. Wuyts et al. (2005) demonstrated that, depending on the industry, organisational and strategic proximity are sometimes more important in the formation of alliances. And the literature on economic geography is coherent on the relevance of geographic distance in knowledge transfer; the greater the distance, the more knowledge decays (Boschma 2005). Nevertheless, since our study is concerned with knowledge sharing, it is more appropriate to concentrate on cognitive distance.

[7] In a dynamic sense, cognitive overlap tends to increase with cooperation intensity Mowery et al. (1998). Thus, it is expected that a firm will reconsider its cooperation decisions depending on cognitive distance. Alliances may be discontinued when partners become too close and previously discontinued alliances may be re-formed if the partners have become sufficiently distant in terms of their knowledge endowment.

certainties" (March 1991, p. 71)[8] as well as the common classification of R&D into basic and applied research. As Cassiman et al. (2002) showed, by doing basic R&D a firm can effectively access incoming knowledge spillovers which then help to increase the efficiency of own applied R&D.

In this sense, absorptive capacity is no longer a passive by-product of R&D, but an explicit part of the firm's strategy. This strategic necessity is even more important when the external knowledge source (from which a firm desires to learn) is not close to its prior knowledge. This is also true when the knowledge, such as that which comes from universities and research institutes, is not directly applicable to the needs of the firm. In this case, CL (p. 572) argue that a firm's capacity to appropriate the knowledge increases as the firm invests more in R&D. This argument is extended with the distinction between inventive and absorptive R&D; it can now be noted that it is not routine R&D but explicit investments in the form of absorptive R&D that facilitates the build-up of absorptive capacity. At the same time, firms need to build up a certain level of capacity to generate own knowledge through inventive R&D.[9] Consequently, firms are faced with the strategic decision of how to optimally allocate resources between inventive and absorptive R&D, which, though complementary, are mutually exclusive. This constitutes an investment trade-off that holds important implications for a firm's learning abilities and cooperation preferences.

Historically, modeling studies have treated the R&D investment and cooperation decisions of firms only with respect to exogenous spillovers (see De Bondt 1996, for an overview). Typically, such spillovers, especially when they are symmetric, have a negative effect on strategic R&D investments. At the same time, they incentivise firms to engage in cooperation and to make bilateral investment commitments. Later models account for absorptive capacity and show that technological heterogeneity, as reflected in relatively high (exogenous) spillover rates, incentivises the build-up of absorptive capacity (Hammerschmidt 2009). Even when spillovers are endogenous, as is the case in the model of Cantner and Pyka (1998), allocating more resources to absorptive R&D as spillovers increase tends to be a more profitable strategy when compared with other strategies such as the one in which the firm concentrates purely on invention. A limitation of these studies is their failure to account for strategic alliance formation as a way for firms to access complementarities, pool knowledge resources or innovate jointly.

[8]Even in this framework the understandability–novelty trade-off exists. In the context of exploitation, wherein firms are concerned with improving their performance along the same technological trajectory, a high level of mutual understanding is required to reduce transaction costs (Drejer and Vindig 2007; Cantner and Meder 2007). Notwithstanding, since technological opportunities within a certain trajectory tend to decrease continuously according to Wolff's law (Cantner and Pyka 1998), firms seek for more explorative or extensive opportunities, the aim of which is to generate novelty. Consequently, increasing cognitive distance positively influences the value of interactive learning because it raises the novelty value of technological opportunities as well as the possibility of novel combinations of complementary resources. This is, however, only possible as long as the partners are close enough to understand each other.

[9]This is a mechanism that assures the presence of reciprocal incentives for cooperation (Kamien and Zang 2000; Wiethaus 2005).

In more recent models (Cowan et al. 2007; Baum et al. 2010), alliance formation is driven by its probability to succeed in terms of knowledge generation and innovation, as well as the proximity of the potential partner. Among other things, the models present knowledge sharing as a major motivation for alliance formation. In particular, even in the absence of any social capital considerations,[10] empirically founded network characteristics such as repeated alliances, transitivity and clustering can be observed. However, these models treat absorptive capacity as an exogenous parameter which is similar for all firms in the network. Although our model shares some of their features, an important contribution we make is that absorptive capacity is not modeled exogenously. In contrast, it is endogenous and is influenced by the two trade-offs described earlier. Ultimately, cooperation decision is driven by proximity considerations, endogenous absorptive capacity and the cost of partnership in terms of the knowledge spillovers that a potential partner can absorb.

3 The model

In the model, a total of N firms compete within a defined knowledge space. A firm seeks to maximize its profit from generating innovations. It does this by developing absorptive capacity to gain from knowledge spillovers while also maintaining own inventive R&D. Consequently, the firm needs to decide how to allocate its R&D investments between own invention and the development of absorptive capacity. Knowledge spillovers arise voluntarily through inter-firm cooperation and involuntarily from non-cooperative sources. The decision on investment allocation is affected by cognitive distance (from both types of spillovers); larger distances correspond to higher resource heterogeneity or novelty potential but also to larger investments required to absorb them. For the analyses in this paper, these distances are given exogenously.[11] Each firm resolves the investment trade-off and makes a cooperation decision. This decision is influenced by cognitive distance, R&D investments and appropriability conditions. We are particularly interested in the conditions under which cooperation is superior to non-cooperation. To study this, we compare the R&D investments and profits for a representative firm when it engages in R&D cooperation and when it does not.

Some important assumptions are to be noted. Firstly, in making their cooperation decisions, firms consider only their short term potential profits. This assumption reflects firms' behaviour when the frontier of knowledge is rapidly extending, in which case the pressure to innovate quickly is high, or when productive activities

[10] This means that technological fit, rather than social capital factors like trustworthiness and embeddedness, is a major causal force behind alliance formation (Baum et al. 2010). Firms will select partners from whom they can learn significantly and for specific (short-term) purposes. In this sense, multiple partnerships may not be necessary and firms stop their partnership search once they find a technologically fit partner.

[11] In the dynamic setting that we analyse in Savin and Egbetokun (2013), cognitive distance changes according to the innovation success and learning of the firms.

require a rapidly expanding knowledge base, in which case firms need to cooperate so as to gain access to complementary knowledge (Cowan et al. 2007).

Secondly, firms only select one partner and conduct one R&D project at a given period. This is a simplifying assumption that improves the tractability of the model, allowing us to focus exclusively on knowledge sharing between unique pairs of firms, and is computationally more feasible. The cost of scanning the environment is incurred by all firms and is therefore not considered in the analyses.

Thirdly, the reliability and trustworthiness of potential partners is not taken into account in the selection of cooperation partners. This follows partly from the short-termism with which firms approach partner selection. In addition, since the potential partners both have reciprocal incentives for cooperation, their likelihood to misbehave is significantly lower. Otherwise, firms can simply discontinue the partnership in the next period preventing an access to their voluntary spillovers.

Finally, firms are assumed to have perfect information about the knowledge base of other firms.[12] This assumption appears to be rather strong and is in contrast with the common perception that firms have imperfect information about partners' knowledge and motivations (Oxley 1997). However, it finds justification in the fact that the capabilities and strategic focus of potential partners can be easily assessed through massive information that is freely available. For example, a firm's patent portfolio (which can be freely accessed online) contains significant information on its knowledge stock and market value (Hall et al. 2005). Thus, patents constitute a comprehensive representation of the knowledge space in an industry. Note also that investments in screening and understanding this knowledge (e.g., by hiring patent lawyers) can be considered as a separate share of a firm's R&D budget, further justifying the distinction in R&D investments applied in the model. In addition, there are several other channels through which reliable information can be obtained, for example, scientific and technical articles, hiring, and informal networks (see footnote 3 in Baum et al. 2010, for more details on this).

3.1 R&D investments

In accordance with CL, we consider R&D investments as an instrument to stimulate absorptive capacity. However, we consider this capacity to be not a by-product of the total R&D investments but of a separate share of it. Thus, we distinguish between investments directly in R&D that exploit identified technological opportunities (rdi_i) and investments for exploring the environment for technological development (aci_i), together forming total R&D spending (RD_i):[13]

$$RD_i = rdi_i^t + aci_i^t = \rho_i^t RD_i + (1 - \rho_i^t) RD_i. \tag{1}$$

[12]This does not necessarily eliminate the risks associated with innovation. First, firms need to be able to understand the information available, an endeavour which is by itself costly and risky. Then, innovation still runs the risk of failing, irrespective of how well-informed firm's cooperation decisions are.

[13]We abstract from production and the market by treating the R&D budgets as exogenous. In this way, the focus of the model is narrowed to the firm's investment and cooperation decisions, and innovation.

This investment trade-off is shaped by learning incentives including the potential quantity and complexity of external knowledge.

3.2 Knowledge generation

In line with CL, firm i's stock of knowledge in period t (k_i^t) is increased by a quantity comprising the firm's own direct investment in R&D and externally generated knowledge which, in turn, consists of other firms' R&D (rdi_h^t) and knowledge generated by public institutions (ek):

$$k_i^t = \left(rdi_i^t\right)^{\xi} + ac_i^t \left(\delta_n \sum_{h \neq i} rdi_h^t + ek^t\right), \tag{2}$$

where $\xi \in (0, 1)$ is a parameter which defines the rate of return to inventive R&D, $\delta_n \in (0, 1)$ reflects the fraction of knowledge not appropriated by firms and $ac_i^t \in (0, 1)$ is the degree to which firm i can absorb external knowledge, i.e. absorptive capacity. The summation term in Eq. (2) assumes no cooperation between firms, hence no voluntary knowledge spillovers. All firms want to ensure that the value of δ_n is as low as possible.

However, within a cooperative context the situation is different. Besides involuntary spillovers (δ_n), firm i can also appropriate voluntary spillovers (δ_c) from its strategic partner. Thus,

$$k_i^t = \left(rdi_i^t\right)^{\xi} + ac_i^t \left((\delta_c + \delta_n) \sum_{j \neq i} rdi_j^t + \delta_n \sum_{j \neq h \neq i} rdi_h^t + ek^t\right), \ 1 > \delta_c > \delta_n > 0$$

The term $\delta_c + \delta_n$ reflects total spillovers available to a cooperating firm and is always below 1. In a dyadic relationship, only one partner j is present, and it can be assumed that all involuntary spillovers available are included in the total external knowledge ek.[14] Therefore,

$$k_i^t = \left(rdi_i^t\right)^{\xi} + ac_i^t \left(\delta_c rdi_j^t + ek\right). \tag{3}$$

As stated earlier, we assume that firms have a perfect knowledge about the distances to their potential partners and about their R&D budgets. Now, since any particular firm takes a decision on the investments in R&D based on the investment decision of its potential partner, we assume that in any given period each firm forms

[14]This follows partly from our focus on dyadic partnerships. In this sense, knowledge spillovers from other firms not in the dyad and from public organisations together constitute technological opportunities for the dyad.

an expectation, considering the investment decision of the partner to be equal to, e.g., the average from the last few (σ) investment allocations made by the partner:[15]

$$E^i(\rho_j^t) = \frac{\sum_{\iota=1}^{\sigma} \rho_j^{t-\iota}}{\sigma}. \tag{4}$$

With the analysis of a representative agent and exogenous cognitive distance, no interaction of firms is considered and the equality in Eq. (4) simply translates into an assumption of perfect knowledge about the partner's investment allocation (i.e., $E^i(\rho_j) = \rho_j$).[16]

External knowledge, ek, is set as the total inventive R&D investment of companies (N firms in total) in the knowledge space which the firm i can potentially understand, rescaled by the parameter of involuntary spillovers,[17] $\delta_n \in (0, 1)$:

$$ek^t = \delta_n \sum_{i \neq h=2}^{N} rdi_h^t. \tag{5}$$

In the meantime we drop the time argument t to remove the notion of dynamics.

3.3 Absorptive capacity

Absorptive capacity (ac_i) is dependent on two variables: i) the distance ($d_{i\cdot}$) between firm i's knowledge base and external knowledge available and ii) the investments in absorptive capacity (aci_i) made by the firm. Cognitive distance d_{ij} is modeled as the Euclidian distance between the stock of knowledge of the two partners i and j ($\nu_{i\cdot}$ and $\nu_{j\cdot}$), which are independently and randomly attributed to the firms from the interval [0, 1]:

$$d_{ij} = \sqrt{(\nu_{i1} - \nu_{j1})^2 + (\nu_{i2} - \nu_{j2})^2}. \tag{6}$$

We choose a two-dimensional space for a better visualization of results. As earlier mentioned, for the present analyses cognitive distance is given exogenously. In a separate dynamic analysis we allow the distance to vary depending on cooperation intensity.

As explained earlier, shared knowledge is the main motivation for alliance formation between any two firms i and j. Following Wuyts et al. (2005), this knowledge can be represented as the mathematical product of its novelty value (which increases

[15]The exact number of periods constituting a reasonable expectation is best validated in a simulation model (Savin and Egbetokun 2013).

[16]However, in the dynamic setting that we simulate subsequently, Eq. (4) necessarily introduces some uncertainty as the expectation of firm i will not necessarily coincide with the actual investment decision of firm j, which, in turn, is based on its own expectation about firm's i decision: $E^i(\rho_{j,t}) \neq \rho_j = f(E^j(\rho_{i,t}))$.

[17]This fraction is determined by the appropriability conditions which include the patent system in a particular industry and the efficacy of secrecy or other forms of protection of firm j's internal knowledge.

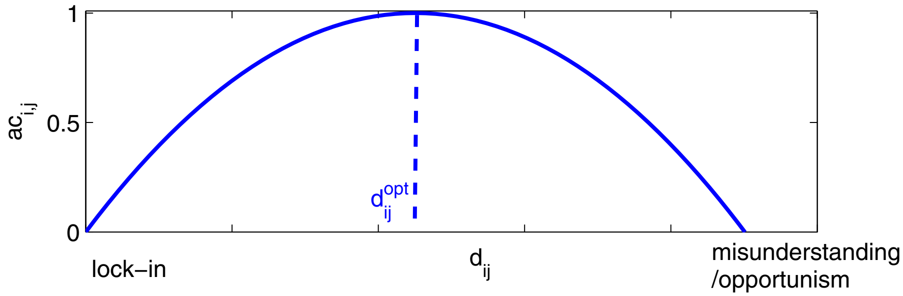

Fig. 1 Absorptive capacity function

in cognitive distance) and understandability (that respectively decreases in cognitive distance):

$$an_{i,j} = (\alpha d_{ij})(\beta_1 - \beta_2 d_{ij}) = \alpha\beta_1 d_{ij} - \alpha\beta_2 d_{ij}^2, \tag{7}$$

And accounting for the stimulating role of investments in absorptive capacity (aci_i):

$$an_{i,j} = \alpha\beta_1 d_{ij}(1 + aci_i^{\psi}) - \alpha\beta_2 d_{ij}^2 = \alpha\beta_1 d_{ij} + \alpha\beta_1 d_{ij} aci_i^{\psi} - \alpha\beta_2 d_{ij}^2\,, \tag{8}$$

where $\psi \in (0, 1)$ reflects the efficiency of absorptive R&D. This investment essentially causes an upward shift in understandability for any given d_{ij} and has decreasing marginal returns. Since the aim of the firm is to maximise the knowledge it absorbs given its current level of absorptive capacity, we proceed by considering absorptive capacity as a function of the knowledge absorbed by i from cooperation with j. Specifically, it is presented as $an_{i,j}$ normalized by its maximum value:

$$ac_{i,j} = \frac{\alpha\beta_1 d_{ij} + \alpha\beta_1 d_{ij} aci_i^{\psi} - \alpha\beta_2 d_{ij}^2}{\frac{1}{4\alpha\beta_2}\left[\alpha\beta_1(1 + aci_i^{\psi})\right]^2} \in [0, 1] \tag{9}$$

A larger d_{ij} increases the marginal impact of aci_i on absorptive capacity $\left(\frac{\partial ac_{i,j}}{\partial aci_i \partial d_{ij}} > 0\right)$, which corresponds with CL (p. 572).[18] In contrast, the effect of d_{ij} on $ac_{i,j}$ is ambiguous: for a given value of aci_i, it is positive $\left(\frac{\partial ac_{i,j}}{\partial d_{ij}} > 0 and \frac{\partial^2 ac_i}{\partial d_{ij}^2} < 0\right)$ until a certain optimal distance is reached and negative $\left(\frac{\partial ac_i}{\partial d_{ij}} < 0\right)$ otherwise (Fig. 1). The maximum of the inverted 'U'-shaped function shifts right (left) with increasing (decreasing) aci_i (Fig. 2), allowing a firm to adopt its absorptive capacity to the actual distance from its cooperation partner. The latter characteristic corresponds to the empirical fact that investments in absorptive capacity raise the optimal distance between cooperation partners (de Jong and Freel 2010; Drejer and Vindig 2007).

[18] Note that while cognitive distance is symmetric (i.e. $d_{ij} = d_{ji}$), $an_{i,j}$ and $ac_{i,j}$ are asymmetric. This is because the investment trade-off is not solved by the two companies identically (i.e. absorptive R&D investments are not necessarily the same for the two companies).

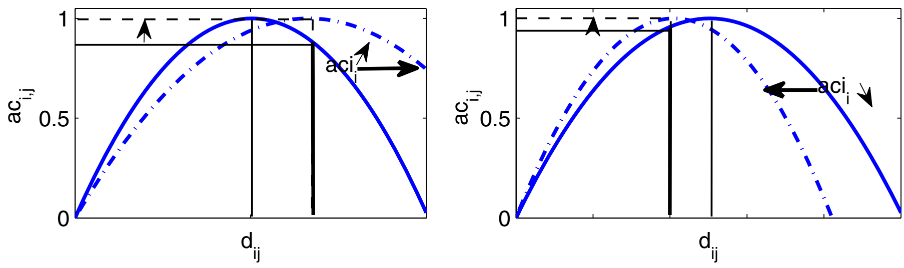

Fig. 2 Dynamics in absorptive capacity function. As company i increases its investments in absorptive capacity (aci_i), the optimal distance to its cooperating partner increases. Thus, for the larger distance, i has a higher absorptive capacity by increasing its investments (*left plot*). The opposite is true for the lower distance (*right plot*)

It is clear from Eq. (9) that when $d_{i.} = 0$ absorptive capacity equals zero. This is because if there is no difference between firm i's own knowledge and the external one, the novelty value is zero even if understandability is maximal. In this way, absorptive capacity ($ac_{i,.}$) is modeled explicitly at the level of interactive learning;[19] and it captures not only the ability to understand external knowledge, but also the ability to explore the environment and to identify novel knowledge.

It should be noted that the cognitive distance of firm i from from external knowledge ek (i.e. d_{iek}) is not necessarily the same as that from firm j (i.e. d_{ij}). In this study we consider it as the average distance to all other firms in the knowledge space:

$$d_{iek,t} = \frac{\sum_{i \neq k=2}^{N} d_{ik}}{N-1}, \tag{10}$$

so that the maximum distance to the external knowledge does not exceed the maximum distance to a single potential partner in this space. Thus, for the same level of absorptive R&D, the absorptive capacity directed on each of the two sources of spillovers will be different.[20] When this is accounted for, Eq. (3) transforms into:

$$k_i = rdi_i^{\xi} + ac_{i,j}\left(\delta_c rdi_j\right) + ac_{i,ek}\,(ek)\,. \tag{11}$$

Therefore, one should not misinterpret ek as any sort of knowledge which can be transferred automatically. Like voluntary spillovers, the involuntary ones - though codified - also require the effort of absorption: a firm has to have sufficient absorptive capacity to identify and assimilate this new knowledge.

Without an R&D partner, the knowledge to be generated by firm i is different (ek is the only source of external knowledge):

$$k_i^{\text{generated alone}} = rdi_i^{\xi} + ac_{i,ek}\,(ek) \text{ as } \delta_c = 0. \tag{12}$$

[19]This is similar to the conceptualisation by Lane and Lubatkin (1998) of absorptive capacity as 'a learning dyad-level construct'.

[20]As in Eq. (9), $ac_{i,ek} = f(d_{iek})$.

3.4 Innovation and profit

Innovation is perceived as a process which involves recombination of heterogeneous resources. Thus, the size of a potential innovation is defined by the amount of knowledge (k_i) generated. When the firm does not form a partnership, its profit (Π_i) is not affected by voluntary spillovers. In a partnership, however, the profit of the firm decreases proportionally with the amount of knowledge spillovers ($ac_{j,i}\delta_c rdi_i$) that the partner can absorb (which is essentially a constituent part of k_j that reduces the appropriability of k_i). This is in contrast to CL where Π_i is reduced proportional to the knowledge generated by the partner (k_j).[21] This 'cost of partnership' or, in the words of CL, 'effect of rivalry' affects the choice of an R&D partner. To avoid the problem of increasing Π_i for $ac_{j,i}\delta_c rdi_i < 1$, we introduce a 'natural' leak-out that is fixed and equal to 1.

$$\Pi_i = \begin{cases} k_i^{\text{generated in cooperation}} / \left(1 + ac_{j,i}\delta_c rdi_i\right) & \text{if } i \text{ has a partner } j, \\ k_i^{\text{generated alone}} & \text{if } i \text{ has no partner.} \end{cases} \quad (13)$$

One way of interpreting the profit function in case of partnership in Eq. (13) is a split of property rights over a certain invention (new technology) converted into a monetary value. Since this technology may be used in different applications, the split is not necessarily exact; however, appropriation of rights over the invention is reduced by the amount of spillovers to a competing partner. Thus, the functional form suggested can have a meaningful (although not necessarily exclusive) economic interpretation and also follow the assumptions on the functional form from CL (see above). In general, the variable Π can be interpreted as an incremental innovation based on a new recombination of knowledge resulting from a firm's continuous R&D effort and from which the firm derives profits.[22] Therefore, henceforth Eq. (13) is referred to as profit and used in our study as a main indicator of firms' performance.

4 Optimal decision making

In the following we discuss the optimal strategy of firm i in i) solving the investment trade-off and ii) forming a partnership. Our interest is in how absorptive capacity (derived from R&D resource allocation, ρ_i), cognitive distance (d_{ij}), appropriability conditions (δ_c) and technological opportunities (ek) affect the benefits from cooperation. To study this, we resolve the investment trade-off for a representative firm in two scenarios (cooperative and non-cooperative) and compare the results in terms of innovative profit.

---

[21] Recall that in CL $\frac{\partial \Pi_i}{\partial k_i} > 0$, $\frac{\partial \Pi_i}{\partial k_j} < 0$ and $\frac{\partial \Pi_i}{\partial k_i \partial k_j} < 0$.

[22] Once we address the dynamics of firms in the knowledge space, the notion of radical innovation will also be required. However, for the sake of brevity we do not include its discussion in this study.

4.1 Investment trade-off

For certain levels of the distance d_{ij} that maximises understandability and novelty, firm i is incentivised to invest in absorptive R&D to maximise the amount of external knowledge absorbed. The trade-off that the firm faces is how to optimally distribute its total R&D investment between the creation of own knowledge and the improvement of absorptive capacity. This necessitates a comparison of the marginal returns to each type of investment with respect to the profit gained. Absorptive R&D begins to pay off when it generates a marginal return that is equal to that of inventive R&D:

$$\frac{\partial \Pi_i}{\partial aci_i} = \frac{\partial \Pi_i}{\partial rdi_i} \tag{14}$$

Using Eqs. (13), (12), (11), (9) and (1), we obtain (for derivation see Appendix 1 in Egbetokun and Savin 2014) the condition for the R&D investment that satisfies Eq. (14):

$$\begin{cases} \mathrm{F}(\rho_i) = 0 & \text{if } i \text{ has a partner } j, \\ \mathrm{F}^{\mathrm{a}}(\rho_i) = 0 & \text{if } i \text{ has no partner.} \end{cases} \tag{15}$$

As Eq. (15) is a highly complex non-linear function with multiple local minima depending on the particular set of parameter values applied, it is a non-trivial problem to find the value of ρ_i satisfying the condition.[23] For this reason we apply a heuristic optimisation technique, in particular, Differential Evolution (see Storn and Price (1997) and Blueschke et al. (2013)) that is able to identify a good approximation of the global optimum in Eq. (15) for different sets of calibrating parameters as long as they satisfy the conditions stated above (see Egbetokun and Savin (2014) for details). It is important to note that this optimization is performed solely on current expected profits as it was done, e.g., by Klepper (1996). Such a short-term horizon consideration together with the uncertainties about partners' investment decision and the exact outcome of partnership matching does not allow pursuing any long-term equilibrium (which is also not our aim).

4.2 Partnership formation

Since larger distances (until a certain optimum level) increase the marginal returns to new knowledge generated, it follows that each firm prefers to select a cooperation partner at the largest distance possible to maximise the novelty value of the R&D cooperation. At the same time, the partner choice is essentially constrained by understandability such that the firm i chooses a partner which it can also understand. In addition, the firm also takes into account the costs of partnership as a result of spillovers from its R&D efforts. Ultimately, the decision to cooperate (or not) is a profit-maximising one which depends on the potential profit generated when

[23] A deterministic iterative solution (e.g., according to the fixed-point theorem) is also not applicable as the function does not necessarily always converge to a $\rho_i \in [0, 1]$ for all possible combinations of parameters.

working alone in comparison with profit generated by cooperating with the most 'fitting' partner:

$$\max\left(\Pi_i^{\text{generated alone}};\ \Pi_i^{\text{with any of the possible partners}}\right). \tag{16}$$

To this end, the simulation in the basic case can proceed as follows. First, all exogenous parameters (α, β_1, β_2, ψ, ξ, η, γ, ρ_j, δ_c, ek (the latter three can be simulated with different scenarios)) must be set.[24] This also includes a random distribution of the initial stocks of knowledge ($\Rightarrow$ set d_{ij}) and aggregated R&D budgets (RD) for all firms.

Second, in each period one needs to solve the investment trade-off of each company ($\rho_.$) for all potential partners, considering the expectation about other firms' investments in R&D to be known. After that, the amount of knowledge $k_.$ to be generated by each company either alone (standalone mode) or in partnership with any of the firms in the knowledge space is estimated. Based on this information the most lucrative partner for each company can be selected by maximizing profit from R&D activity Π_i.

Third, although the most lucrative partner for each firm is identified, partnership formation is a non-trivial task in this model. The reason is that the incentives of a firm i to build a partnership with firm j are asymmetric: although distance between the partners is the same, the decision on the investment trade-off in R&D is individual for each company. Hence, there is no 'Nash stable network'.[25] Therefore, the model we build can be considered to be 'non-equilibrium' model basing on the functional dependencies described and following certain matching rules given below:

- *Unilateral matching*: in each period in a random order firms sequentially identify their most fitting partner. Once the partner is found, partnership is formed (i.e. the chosen firm simply adjusts its ρ to the given partner).
- *Reciprocal matching*: if firm i identifies firm j as the most lucrative cooperation partner and is itself among the 'top' 5 % of the companies with whom firm j would cooperate, then they build a partnership.
- *A 'popularity contest'*: one counts for how many firms each company is the most lucrative one, the second most lucrative, ... After that the firms are ranked according their popularity and choose a partner in the order of the ranking.

It remains for simulation experiments to decide which of the scenarios described fits best. The extensive simulation is described in Savin and Egbetokun (2013). In the following, only some illustrative results for one firm in two scenarios (cooperative and non-cooperative) are demonstrated.

[24] For illustrative reasons we take a single set of parameter values for two firms satisfying their constraints. In particular, $\alpha = \sqrt{2}/50$, $\beta_1 = \sqrt{2}$, $\beta_2 = 1$, $\psi = \xi = 0.4$, $RD_i = RD_j = 0.2$, $\delta_c = 0.5$, $ek = 1$, $\rho_j = 0.5$, $d_{iek} = \sqrt{2}/1.001$ and $d_{ij} = \sqrt{2}/1.01$. These values were chosen to demonstrate on a single set of graphs the complex shape of the ρ and Π functions in response to changes in the variables of interest.

[25] 'a stable network is one in which for each agent (or pair of agents) there is a payoff maximizing decision about which link to form' (Cowan et al. 2007, p. 1052)

Table 1 Comparative static results

Effect	CL	Our model
$\partial\Pi_i/\partial d_{ij}$	positive	ambiguous
$\partial\Pi_i/\partial\delta_c$	ambiguous	ambiguous
$\partial\Pi_i/\partial\rho_j$	–	positive
$\partial\Pi_i/\partial ek$	ambiguous	positive

4.3 Comparative statics

In CL, absorbed external knowledge is endogenous and influenced by R&D investments, which is itself affected by the ease of learning, intra-industry spillovers and technological opportunities.[26] The effects of the latter group of parameters are similar for both R&D investment and the payoff it generates for the firm. However, the extensions we make in our study lead to different results. First, the distinction between absorptive (aci_i) and inventive (rdi_i) R&D implies that the learning effects of research are driven by only the investments in the build-up of absorptive capacity. Second, explicitly accounting for voluntary spillovers introduces the effect of reciprocal incentives in resource allocation and partnership formation. In addition to its own resource allocation problem, each firm takes into account the investment decisions of the potential partners.

Moreover, in contrast to CL, we model in the context of inter-firm cooperation and, therefore, concentrate on cooperation decision and innovation-driven profit rather than just on R&D investments. As it is clear from comparing Eqs. (1) and (13), the parameter effects on the firm's R&D investments ($\partial RD_i/\partial\cdot$) and its payoff in terms of profit ($\partial\Pi_i/\partial\cdot$) are not necessarily similar. In Table 1 we summarise our results in comparison to CL[27] focusing on the latter group of effects (since the R&D profit presents the main motivation for firms to engage in cooperation in our study), while Fig. 3 illustrates them in detail for the cooperating and non-cooperating scenarios. With reference to this figure, we elaborate on the effects of each parameter in the following subsections. Note at this point that the results (primarily, investment allocation) illustrate the optimization outcome (see Eq. (15)) - a best option out of the set of alternatives, which by no means guarantees success in innovative performance for the reasons stated earlier in this chapter.

4.3.1 Cognitive distance

As seen from the bottom leftmost plot in Fig. 3, the cognitive distance d_{ij} between cooperating partners has an ambiguous effect on R&D profits. A small distance

[26]For the sake of comparison, CL's ease of learning is analogous to our cognitive distance, intra-industry spillovers - to appropriability conditions and technological opportunities - to external knowledge.

[27]Note that by construction, in CL firm i's marginal returns to R&D have the same effect on marginal returns generated by the firm in terms of profit.

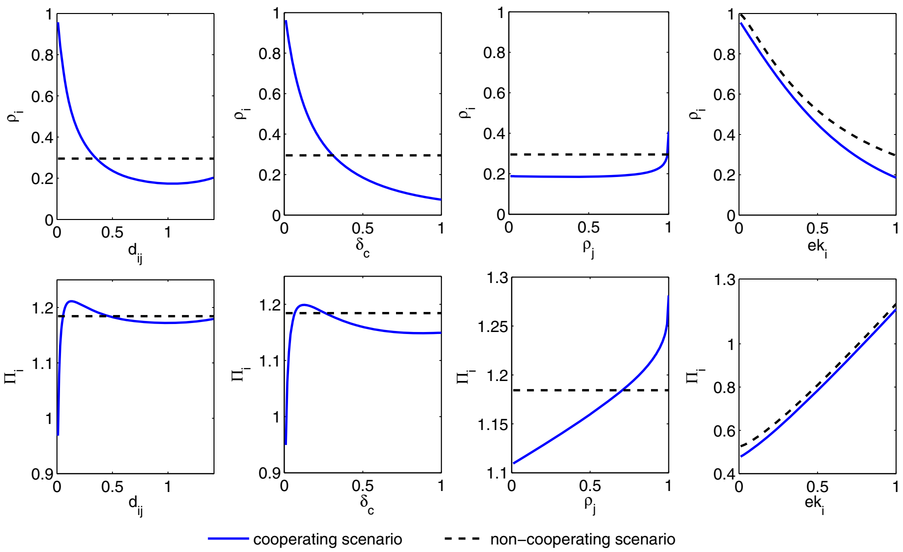

Fig. 3 Comparative statics for the investments (ρ_i) and profits (Π_i) of firms

(which does not require absorptive investments) positively affects R&D profit. This is because the firm can dedicate most of its R&D budget to invention and it suffers little or no negative appropriation in return (top leftmost plot). In this range, R&D profits in the cooperation scenario consistently increase and overtake the levels in the non-cooperation scenario because the cooperating firm can complement its own knowledge with increasingly novel knowledge from the partner. This, however, requires raising investments in absorptive capacity to maintain the gain from the partner's knowledge. Consequently, inventive R&D reduces. The R&D profits also reduce since, with increasing cognitive distance, the cost of partnership in terms of spillovers increases as well.

At a very large distance, an 'understandability problem' arises such that new knowledge cannot be absorbed as efficiently any longer. This problem cannot be overcome by simply increasing investments in absorptive capacity. In this range, increasing absorptive R&D investments becomes sub-optimal, and as a result, some resources are shifted back to inventive R&D. Clearly, the standalone strategy is more lucrative only when the distance to a potential partner is either too large (understandability problem) or too small (no novelty). For a range of cognitive distance between these two extremes, the cooperative strategy is better.

Taken together, these results imply that firms' decision to cooperate and the choice of a cooperation partner is heavily influenced by the investments they are willing to make in order to establish efficient collaboration. And in contrast to CL, where the ease of learning has a strictly positive effect on R&D investments and profit when cooperation is not accounted for, the effect of cognitive distance on profit has an inverted 'U' shape in the context of cooperation.

4.3.2 Appropriability conditions and external knowledge

Appropriability conditions (δ_c) and external knowledge (ek) show similar effects on the amount of knowledge generated by the firm. $\partial k_i/\partial \delta_c$ and $\partial k_i/\partial ek$ are strictly positive suggesting that the appropriability conditions in a cooperative setting as well as the amount of external knowledge raise the ability of the firm i to create new knowledge from external sources. Consequently, firm i is incentivised to reallocate its investments from inventive to absorptive R&D. More resources are devoted to absorptive capacity which generally results in a higher level of new knowledge (k_i) generated from the cooperation.

However, appropriability conditions (δ_c) and external knowledge (ek) show different effects on the R&D profits generated by the firm. In contrast to ek (which has a strictly positive effect as shown in the lower rightmost plot in Fig. 3), δ_c has an ambiguous effect on R&D profit (bottom second plot in Fig. 3). On the one hand, the firm i benefits from voluntary spillovers from its cooperation partner and experiences increasing profits. As voluntary spillovers increase, the profits rise consistently and overcome the levels in the standalone strategy. On the other hand, voluntary spillovers from i also contribute to the knowledge stock of the cooperating partner. This causes a reduction in firm i's R&D profit. The combination of these two effects leads to an inverted 'U'-shaped relationship between δ_c and Π_i. This relationship is such that the cooperation is only better for an intermediate range of voluntary spillovers. When cooperation intensity is too low, the additional knowledge gained through voluntary spillovers will be too low to justify investments made to absorb it. When cooperation intensity reaches its maximum level, the threat of large spillovers is more pronounced. In both of these latter scenarios, the non-cooperative strategy is more attractive.

The ambiguous effect of δ_c on profits is necessarily affected by the absorptive R&D budget of the partner: if it is small enough, firm i can benefit from intensive cooperation not being afraid that its partner absorbs much.[28] In contrast, if the partner has sufficiently high absorptive capacity, firm i's losses from a larger δ_c can exceed its benefits. This particular result contrasts with CL where the effect of appropriability conditions is modified by the ease of learning. In our model, the effect of cognitive distance in this respect is captured in absorptive capacity which has the inverted 'U'-shaped form representing the understandability/novelty trade-off. With a very large cognitive distance the appropriability conditions may not matter at all as the partners have difficulties understanding each other.

Since technological opportunities are equally available for both cooperating and non-cooperating firms, R&D profit in relation to ek is only dependent on the firm's absorptive capacity (see Eq. (12)). The relationship varies because of the different number of factors involved - for the cooperating and non-cooperating scenarios - in the firm's optimal decision making (see Appendix 1 in Egbetokun and Savin 2014).

[28] For instance, setting investment decision of the partner $\rho_j = 0.75$, Π_i in the cooperating scenario shows only a small downturn and then rises consistently outperforming the non-cooperating scenario.

In particular, when the cost of cooperation is high, as in the representative case that we analyse, the non-cooperative strategy consistently yields superior performance benefits (lower rightmost plot in Fig. 3). This result is reversed at lower levels of cooperation intensity (e.g. at $\delta_c = 0.2$).

4.3.3 R&D investments and absorptive capacity

The investment decision of the partner ρ_j has an ambiguous effect on firm i's investment allocation, but not on its profit (where it is strictly positive). This is because as ρ_j increases, it contributes to the pool of external knowledge i can benefit from. This creates an incentive to increase investments in absorptive capacity. However, ρ_j reaching its maximum values (close to 1) implies that the cooperating partner invests very little in the build-up of absorptive capacity. Thus, knowledge spillovers from firm i to j that can be absorbed do not present a big threat for firm i's inventive R&D any longer. This leads to a large change in i's investment allocation and, consequently, its R&D profit. In this context, the non-cooperative strategy is more lucrative only when the partner mostly invests in absorbing knowledge and not in its generation ('free rider' problem). When the partner heavily invests in invention, it is obviously better to cooperate.

5 Conclusion

In this paper we set out to model absorptive capacity within the framework of inter-firm cooperation such that the capacity of a firm to appropriate external knowledge is not only a function of its R&D efforts but also of the distance from its partner. This framework allows to account for recent empirical findings and to examine factors affecting the firm's choice on whether to engage in R&D cooperation. In comparison with the original model of Cohen and Levinthal (1989), our results show some marked differences. Besides, some insights into the cooperation and R&D investment preferences of firms are provided.

First of all, the cognitive distance between a firm and its cooperation partner has an ambiguous effect on the profit generated by the firm. Thus, a firm chooses its cooperation partner conditional on the investments in absorptive capacity it is willing to make to solve the understandability/novelty trade-off. Firms possessing a larger R&D budget have the possibility to engage in cooperation with firms located further away in terms of cognitive distance. This is in keeping with empirical studies of alliance formation (Lin et al. 2012; Nooteboom et al. 2007; Wuyts et al. 2005). If the partner is too close or too far, no efficient collaboration can be established.

Next, though appropriability conditions in the framework of cooperation also have an ambiguous effect on profits, this effect does not necessarily become greater (positive) with a larger cognitive distance as in CL. At a very large cognitive distance the appropriability conditions may not matter at all as the partners cannot understand each other. In this respect, a more important variable is the partner's absorptive capacity. In our formulation, absorptive capacity is a more complex construct presenting the interaction between a firm's absorptive R&D and cognitive distance. The larger the partner's absorptive capacity, the larger the portion of knowledge spillovers that this partner can assimilate and the more risky cooperation becomes. This complex relationship, in our view, partly explains the caution that firms have in engaging in R&D cooperation and the very detailed contracts related to the respective agreements (see, e.g., Atallah 2003). The finding that cooperation is a more profitable strategy than 'going it alone' only for an intermediate range of voluntary spillovers is consistent with an empirical finding in the literature on alliances. Intense cooperation between the same firms imply increasing cognitive overlap and reducing learning and innovation potential of the alliance (Mowery et al. 1996).

Finally, external knowledge, that is knowledge available outside the framework of cooperation, as well as the partner's inventive R&D investments have positive effects on the R&D profit. While the latter distinguishes our model from CL (where such a variable is not explicitly considered), the former demonstrates an effect that somehow contradicts CL. The reason is that according to CL where R&D investments are considered as one expense item, external knowledge reduces incentives to own R&D on the one hand, but incentivises investments for absorptive capacity on the other hand. Since we distinguish between inventive and absorptive R&D, the dynamics from CL is contained in the focal firm's reaction in investment allocation, while the total effect on the R&D profit is strictly positive. Also it is clear that the knowledge about the partner's R&D investment allocation presents an important asset for any firm in our model. Ability to foresee this split allows a company to avoid opportunistic behaviour from potential partners (i.e. 'free riders' with low inventive R&D) and better resolve the two trade-offs in their decision making (optimal cognitive distance and optimal split of investments).

The analyses in this paper have been carried out for a single representative firm. This setting has allowed us to explicitly focus on a major aim of this paper, namely, analysing the condition under which it is better to cooperate in R&D than to stand alone. Although the analyses have led to some useful results, a full-blown dynamic analysis of a population of firms is potentially more interesting. Such analysis is beyond the scope of the present paper. In a follow-up paper (Savin and Egbetokun 2013), we present a dynamic model of network formation where firms ally purely for knowledge sharing and we examine the effects of networking on firm performance.

References

Arrow K (1962) Economic welfare and the allocation of resources for invention. In: Nelson R (ed) The rate and direction of inventive activity. Princeteon University Press, Princeteon, pp 609–626

Atallah G (2003) Information sharing and the stability of cooperation in research joint ventures. Econ Innov New Tech 12(6):531–554

Bamford J, Ernst D (2002) Managing an alliance portfolio. McKinsey Q 3:29–39

Baum JAC, Cowan R, Jonard N (2010) Network-independent partner selection and the evolution of innovation networks. Manag Sci 56(11):2094–2110. doi:10.1287/mnsc.1100.1229

Blueschke D, Blueschke-Nikolaeva V, Savin I (2013) New insights into optimal control of nonlinear dynamic econometric models: application of a heuristic approach. J Econ Dyn Control 37(4):821–837

Boschma R (2005) Proximity and innovation: a critical assessment. Reg Stud 39(1):61–74

Brusoni S, Prencipe A, Pavitt K (2001) Knowledge specialization, organizational coupling, and the boundaries of the firm: why do firms know more than they make? Adm Sci Q 46(4):597–621

Cantner U, Meder A (2007) Technological proximity and the choice of cooperation partner. J Econ Interac Coord 2:45–65
Cantner U, Pyka A (1998) Absorbing technological spillovers: simulations in an evolutionary framework. Ind Corp Chang 7(2):369–397
Cassiman B, Pérez-Castrillo D, Veugelers R (2002) Endogenizing know-how flows through the nature of r&d investments. Int J Ind Organ 20(6):775–799
Cohen W, Levinthal D (1989) Innovation and learning: the two faces of R&D. Econ J 99(397):569–596
Cowan R, Jonard N, Zimmermann J (2007) Bilateral collaboration and the emergence of innovation networks. Manag Sci 53(7):1051–1067
De Bondt R (1996) Spillovers and innovative activities. Int J Ind Organ 15(1):1–28
Dettmann A, von Proff S (2010) Inventor collaboration over distance – a comparison of academic and corporate patents. Tech. Rep. 2010–01, Working Papers on Innovation and Space
Dosi G (1982) Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. Res Policy 11(3):147–162
Drejer I, Vindig A (2007) Searching near and far: determinants of innovative firms' propensity to collaborate across geographical distance. Ind Innov 14(3):259–275
Egbetokun E, Savin I (2014) Absorptive capacity and innovation: when is it better to cooperate? In: Foster J, Pyka A (eds) Co-evolution and complex adaptive systems in evolutionary economics, Springer series economic complexity and evolution. Springer, Berlin, Heidelberg
Fehr E, Gächter S (2000) Fairness and retaliation: the economics of reciprocity. J Econ Perspect 14:159–181
Flatten T, Engelen A, Zahra S, Brettel M (2011) A measure of absorptive capacity: scale development and validation. Eur Manag J 29(2):98–116
de Fraja G (1993) Strategic spillovers in patent-races. Int J Ind Organ 11(1):139–146
de Jong J, Freel M (2010) Absorptive capacity and the reach of collaboration in high technology small firms. Res Policy 39(1):47–54
de Man AP, Duysters G (2005) Collaboration and innovation: a review of the effects of mergers, acquisitions and alliances on innovation. Technovation 25(12):1377–1387
Gilsing V, Nooteboom B, Vanhaverbeke W, Duysters G, van den Oord A (2008) Network embeddedness and the exploration of novel technologies: technological distance, betweenness centrality and density. Res Policy 37(10):1717–1731
Gulati R (1998) Alliances and networks. Strat Manag J 19(4):293–317
Hall B, Jaffe A, Trajtenberg M (2005) Market value and patent citations. RAND J Econ 36(1):16–38
Hammerschmidt A (2009) No pain, no gain: an R&D model with endogenous absorptive capacity. J Inst Theor Econ 165(3):418–437
Kamien M, Zang I (2000) Meet me halfway: research joint ventures and absorptive capacity. Int J Ind Organ 18(7):228–240
Kim L (1998) Crisis construction and organizational learning: capability building in catching-up at Hyundai motor. Organ Sci 9(4):506–521
Klepper S (1996) Entry, exit, growth, and innovation over the product life cycle. Am Econ Rev 86(3):562–583
Lane PJ, Lubatkin M (1998) Relative absorptive capacity and interorganizational learning. Strat Manag J 19(5):461–477
Lin C, Wu YJ, Chang C, Wang W, Lee CY (2012) The alliance innovation performance of R&D alliances: the absorptive capacity perspective. Technovation 32(5):282–292
March JG (1991) Exploration and exploitation in organizational learning. Organ Sci 2(1):71–87
Mowery DC, Oxley JE, Silverman BS (1996) Strategic alliances and interfirm knowledge transfer. Strat Manag J 17:77–91
Mowery DC, Oxley JE, Silverman BS (1998) Technological overlap and interfirm cooperation: implications for the resource-based view of the firm. Res Policy 27(5):507–523
Nooteboom B (1999) Inter-firm alliances: analysis and design. Routledge, London
Nooteboom B, Haverbeke WV, Duysters G, Gilsling V, van den Oord A (2007) Optimal cognitive distance and absorptive capacity. Res Policy 36(7):1016–1034
OECD (2005) Proposed guidelines for collecting and interpreting technological innovation data: Oslo manual. Organisation for economic cooperation and development, Paris

Oxley J (1997) Appropriability hazards and governance in strategic alliances: a transaction cost approach. J Law Econ Org 13(2):387–409
Powell W (1998) Learning from collaboration: knowledge and networks in the biotechnology and pharmaceutical industries. Calif Manag Rev 40(3):228–240
Powell WW, Grodal S (2005) Networks of innovators. In: Fagerberg J, Mowery DC, Nelson RR (eds) Oxford handook of innovation, vol 3. Oxford University Press, Oxford, pp 56–85
Savin I, Egbetokun A (2013) Emergence of innovation networks from R&D cooperation with endogenous absorptive capacity. Tech. Rep. 13/022, CEB Working Paper
Storn R, Price K (1997) Differential evolution: a simple and efficient adaptive scheme for global optimization over continuous spaces. J Glob Optim 11(4):341–359
Wiethaus L (2005) Absorptive capacity and connectedness: why competing firms also adopt identical R&D approaches. Int J Ind Organ 23(5–6):467–481
Wuyts S, Colombo M, Dutta S, Noteboom B (2005) Empirical tests of optimal cognitive distance. J Econ Behav Organ 58(2):277–302
Zahra S, George G (2002) Absorptive capacity: a review, reconceptualization, and extension. Acad Manag Rev 27(2):185–203