Cognitive distance, knowledge spillovers and localisation in a duopolistic game

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Abstract – Due to the complexity of technological development, inter-firm learning is increasingly taking place as a major avenue for outsourcing new knowledge from complementarity technological sources in order to absorb it into the firm's technological portfolio. Empirical evidence has shown that cognitive distance plays a major role in the effectiveness of knowlegde spillovers that can be generate from inter-firm networks. Drawn upon this literature, the aim of the paper is threefold. Firstly, it provides a rigorous foundation to the theory "external economy of cognitive scope" developed by Nooteboom (2000). Secondly, it endogenises knowledge spillovers in a three-stage R&D duopolistic game by incorporating that theory in this class of games. Thirdly, this game theoretical framework is used to explain in a simple way the strategic location of corporate R&D.

Keywords: technological profiles, cognitive distance, knowledge spillovers, R&D localisation, olipolistic game.

JEL Classification: C72, F23, L13, O32.

1. Introduction

The new economy has marked the full establishment of more integrated technological systems through the fusion of diverse and formerly separated branches of technology. This new techno-socio-economic context has pushed firms to a greater diversification of their technological portfolio in order to have a wide range of competencies distributed across diverse fields (Granstand *et al*., 1997). This corporate strategy is dictated by product and processes interdependency and complexity. Thus, if it underlines the significance of broader technological profiles for the sake of market competition, it also highlights the fact that the boundaries of firms cannot fully encompass any longer the entirety of new knowledge generation required to an innovative company.

Although intra-firm organisational learning is still a major strategy to build-up long-run competitiveness, new trends appear to emerge in corporate learning for the purpose of competition. In fact, the increasingly complex nature of technology has promoted the flourishing of inter-firm relationships with the ultimate aim of outsourcing new knowledge from complementary technological sources and absorbing it into the firm's technological portfolio. However, cognitive distance – understood as distance between corporate technological portfolios – represents a constraint to knowledge outsourcing since *different* technological profiles require a greater effort to match partners' competencies in terms of inter-firm communication. Similarly, *sameness* of corporate technological profiles acts as a deterrent to the common R&D development since few complementarities can be enjoyed by firms competing around an equivalent spectrum of activity (Cantwell and Santangelo, 2002), thus holding a low innovative potential. Conversely, *similarity* - the lack of a complete technological overlap - creates the conditions for inter-firm cooperation, through which complementarities can be enjoyed (*Ibid*.). Therefore, inter-firm cognitive distance plays a major role in the effectiveness of corporate interaction (that is the generation of knowledge spillovers), as outside sources of knowledge "require a "cognitive distance" which is sufficiently small to allow for understanding but sufficiently large to yield non-redundant novel knowledge" (Nooteboom, 2000, 72).

Within this framework, the aim of the paper is threefold. Firstly, by exploiting Granstrand's measure of cognitive distance (Granstrand, 1994), it provides a rigorous foundation to theory of "external economy of cognitive scope" developed by Nooteboom (2000). Secondly, building upon this formalisation and upon the work by d'Aspremont and Jacquemin (1988), we develop a three-stage noncooperative R&D game with endogenous R&D spillovers and analyse the problem of existence of a subgame perfect equilibrium. Unlike the very few works which endogenise the spillover coefficient in this class of games (see e.g. Katsoulacos and Ulph, 1998; Kamien and Zang, 2000), our model provides a rigorous theoretical foundation to the determination of the R&D spillover coefficient based upon Nooteboom's view, which is both theoretically and empirically widely recognised. Thirdly, we apply this game-theoretical framework to explain the strategic location of corporate R&D through the process of interfirm learning.

The paper is articulated in 6 sections. Next section discusses the theoretical framework on cognitive distance and knowledge spillovers building upon the evidence provided by the empirical literature. Section 3 formalises the argument concerning technological profiles and cognitive distance. The basic game-theoretic model is illustrated in section 4. Section 5 provides an application of the model to the localisation of R&D activity by multinational enterprises (MNEs). A few conclusions are drawn in section 6.

2. Cognitive distance and knowledge spillovers

In the new economy, the uncertain and fast pace of technological change together with product-level interdependencies has raised the need for a corporate technological profile more diversified than the product profile. Growing firms need to increasingly diversify in order to develop competencies *distributed* across a large number of technological fields as the mastering of a wide spectrum of technologies may prove to be crucial in the development of new product and process innovations. In this sense, the complexity of technological development, due to the full establishment of more integrated technological systems through the fusion of diverse and formerly separated branches of technology, requires firms to "know more that they make" (Brusoni, *et al*. 2001). The establishment of corporate competencies in information and communications technology (ICT), for instance, by firms operating in all industries reveal to be vital due to the application of these technologies to products and processes as a result of their pervasive nature (Cantwell and Santangelo, 2000; Santangelo, 2001). Therefore, due to the great technological opportunities generated by technological complexity, interrelatedness and fusion, new forms of corporate learning seem to follow inter-firm patterns which enable firms to benefit from great technological spillovers through coordination of corporate internal development (Cantwell and Santangelo, 2002).

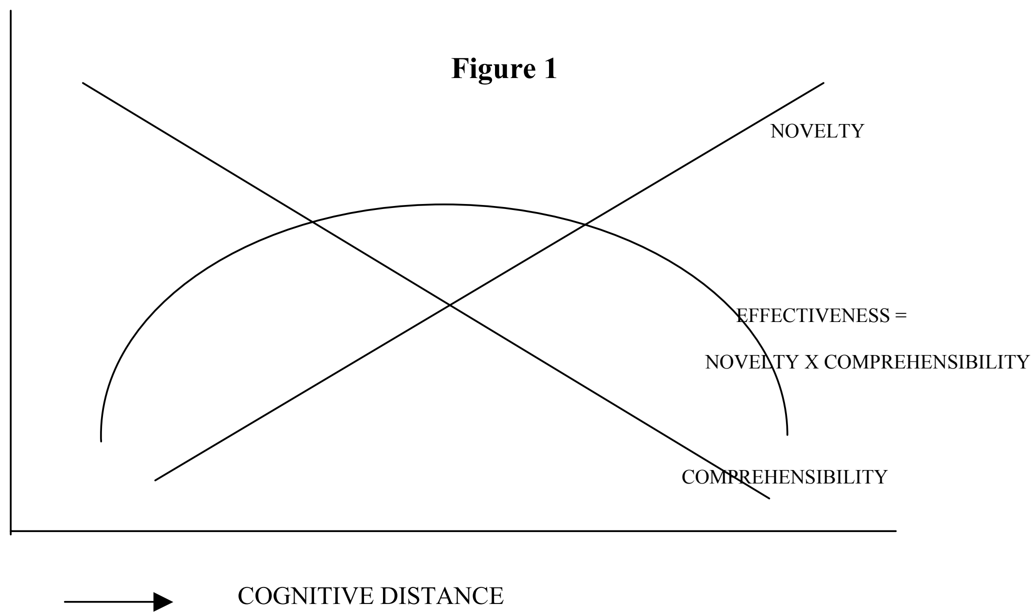
It is interesting to note that the phenomenon of the multi-technology firm has flourished in an era of increasing knowledge codification due to the most recent advances in ICT. Nonetheless, although ICT has allowed an increased codification of a growing range of manufacturing operations, this codification will never be completed due to the persistence of the *uncodified* and *tacit* element of knowledge.[i] In turn, this has two implications. First, firms need to develop in-house (rather than contract out) the knowledge they require in order to have a better understanding of its potential for further applications.[ii] Secondly, as highlighted by Nooteboom (1999), new distantshrinking technologies are unlikely to undermine the value of proximity because the diffusion of codified knowledge amplifies rather than devalues the significance of local tacit knowledge. Due to the complex nature of tacit knowledge, direct and close face-to-face interaction is essential for new technological development.

However, companies do not have the time and the resources to build up all the competencies required. Although intra-firm organisational learning is still a major strategy to build-up long-run competitiveness, new trends appear to emerge in corporate learning for the purpose of competition. In fact, the increasingly complex nature of technology has promoted the flourishing of inter-firm relationships with the ultimate aim of outsourcing new knowledge from complementary technological sources and absorbing them into the firm's technological portfolio (Santangelo, 2002). Therefore, due to the difficulty to individually develop all the knowledge needed, inter-firm networks allow companies to outsource new technological competencies by actively participating in their development. In these networks, companies carry out their R&D by enjoying knowledge spilled over from other firms. Those networks can be shaped in different ways such as STPs and geographical clustering. Regardless of the shape of inter-firm networks, the literature has emphasised the significance of cognitive distance[iii] between the partners for the sake of spillovers effectiveness. As far as STPs are concerned, Mowery *et al*. (1996, 1997), and Santangelo (2000) in the context of the European electronic industry show empirically that the more similar partners' technological portfolios are to one another, the easier it is for them to absorb each other's capabilities. Similarly, Mowery *et al*. (1998) demonstrate that partner selection can be predicted by firms' technological overlap. The empirical literature has also started to explore the role of cognitive distance in corporate geographical clustering. Cantwell and Santangelo (2002) show that strong overlapping of the capabilities of two (or more) firms in a particular field/s acts as a deterrent to the common development of their related R&D in the same location. In this sense, few complementarities can be enjoyed by firms as they are competing around an equivalent spectrum of activity. Conversely, the authors (*Ibid*.) demonstrate that a pattern of co-location[iv] of R&D activity in a particular field/s is likely to be associated with a loose co-specialisation[v] between two (or more) firms in the field/s in question. The lack of a complete technological overlap (and rather the presence of some areas of expertise that distinguish one firm from another) creates the conditions for inter-firm learning through which complementarities can be enjoyed and competencies related to the firm's own technological profile can be absorbed from the external environment into its corporate technological path.

Since cognition is developed in interaction with the physical and social environment, it can be identified with prior knowledge, which "confers an ability to recognize the value of new information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990, 128). All these abilities together have been labelled as absorptive capacity, which is understood as context-dependent, cumulative and path-dependent (Cohen and Levinthal, 1989, 1990). Therefore, in order to have an effective outside source of complementary cognition, an optimal level of cognitive distance is required. Inter-firm cognitive distance should be sufficiently small to allow understanding, but sufficiently large to generate non-redundant novel knowledge (Nooteboom, 2000). In this sense, following Nooteboom (*Ibid*.) the effectiveness of corporate interaction (that we interpret as knowledge spillovers) can be decomposed into two elements, i.e. *comprehensibility* and *novelty*, as graphically illustrated in Figure 1.

A small cognitive distance allows greater comprehensibility, but yields redundant, novel knowledge. Conversely, a large cognitive distance allows limited comprehensibility, although yielding non-redundant, novel knowledge. Firms sharing similar cognition have *similar* perceptions, interpretations and evaluations. Therefore, they understand each other actions and expressions. This implies that they can tell each other's something new (although related to the partner's cognitive framework) and still communicate smoothly on the grounds of their common background. Therefore, a certain degree of cognitive distance is needed since it ensures that firms can connect their cognitive frameworks and being innovative (absorptive capacity) as well as they can easily communicate between each others (communicative capacity). Conversely, if firms share exactly the *same* cognition, there will be a reduction of the innovative potential as they think alike, while, if their cognitive distance is greater, there will be a difficulty in communications.

Figure 1



Source: Nooteboom (2000, 72).

On these grounds, it is possible to distinguish three possible scenarios. First, a complete overlap of firms' technological profiles (*technological sameness*) can be associated to a lack of inter-firm knowledge development (either through alliances or geographical clustering). That is, there is little scope for collaboration for firms sharing the same knowledge for competitive as well as for cognitive reasons. Technological sameness implies that competition around an equivalent spectrum of activity acts as a deterrent to inter-firm knowledge outsourcing. In cognitive terms, although the comprehensibility between the companies involved is high, the novelty that the interaction can generate is low (Nooteboom, 2000). Conversely, a complete lack of overlap of firms' technological profile (*technological dissimilarity*) can be associated to a lack of inter-firm knowledge development. If a large cognitive distance has the merit of novelty (i.e. variety is greater), it also holds a problem of corporate communicability since firms lack a common ground of experience and skills enabling them to speak a mutual understandable language. Instead, an overlap of firms' technological profiles which leaves some areas of distinctiveness (*technological similarity*) can be associated to a pattern of inter-firm interaction for the sake of knowledge development. Firms sharing some common knowledge can communicate with each other as a result of the mutual understanding of their common ground. Similarly, the areas of distinctiveness will leave space and scope for externalities generated by corporate interaction. Thus, technological similarity steams from an optimal cognitive distance promoting effectiveness of learning, which results from an optimal combination of comprehensibility between the partners and novelty arising from variety of knowledge (*Ibid*.). Thus, successful spillovers of tacit knowledge depend on inter-firm cognitive distance.

In what follows, we are interested in providing a rigorous foundation to the theory according to which cognitive distance affects knowledge spillovers as well as in exploring analytically the implications of different degrees of cognitive distance for localised knowledge spillovers. Following Glaeser *et al*. (1992), locational spillovers can be classified into: Marshall-Arrow-Romer (MAR) spillovers arising from specialisation and fed by local monopoly which restricts the flow of ideas to competitors; Porter's spillovers arising from specialisation, but fed by competition which fosters imitation and innovation; and Jacobs' spillovers arising from industry variety within a given location and stimulated by competition. Our attention is here devoted to intra-industry spillovers boosted by inter-firm competition (Porter's spillovers). Although we are concerned with intra-industry spillovers, we believe that cognitive distanced is a key element in the generation of inter-firms spillovers also in the case of inter-industry spillovers as empirically confirmed by empirical findings (see for example Cantwell and Santangelo, 2002). However, in this study we leave this issue on the side, although scheduling it for future research.

3. Technological profiles, cognitive distance and knowledge spillovers

Let (X, τ) be a compact topological space. Denote by $\mathcal{C}$ the collection of nonempty closed subsets of X, by $\mathcal{B}$ the Borel σ-algebra generated by $\mathcal{C}$ and by μ the Borel measure defined on $\mathcal{B}$. We assume that μ assignes finite measure to every compact set. The usual symbols $\cup$ and - are employed to indicate, respectively, set-theoretical union and subtraction. Moreover, let us suppose that A and B are two subsets of X, then the symmetric difference between A and B is defined as follows: $A\Delta B \equiv (A-B)\cup(B-A)$. Note that $A\Delta B = (A\cup B)-(A\cap B)$(Taylor, 1966, 13).

In what follows, the generic element x of set X is interpreted as an "idea" and set X is interpreted as the set of ideas possibly owned by a firm while any element t of $\mathcal{C}$ is interepreted as the knowledge available to a given firm (its *technological profile*).[vi, vii] We measure the "size" of the technological profile t by the number $\nu(t)$, where $\nu \ll \mu$, i.e. ν is absolutely continuous with respect to μ (see Royden, 1988, 276).

Following Granstrand (1994, 216), we measure the technological distance (the cognitive distance) between two technological profiles t_1 and t_2 by the following function: $d(t_1, t_2) = \nu(t_1 \Delta t_2)/\nu(t_1 \cup t_2)$ if $t_1, t_2 \neq \emptyset$ and $d(t_1, t_2) = 0$ otherwise. It is possible to show that d is actually a metric on $\mathcal{C}$ (Granstrand, 1994, 217), moreover, it has value 0 if $t_1 = t_2$ and value 1 if $t_1 \cap t_2 = \emptyset$, finally, it is an decreasing function of the size of "common knowledge" $t_1 \cap t_2$ and an increasing function of the size of the non overlapping knowledge $t_1 \Delta t_2$. For future reference, notice that, by the property of symmetric difference, one obtains $d(t_1, t_2) = 1-(\nu(t_1 \cap t_2)/\nu(t_1 \cup t_2))$.

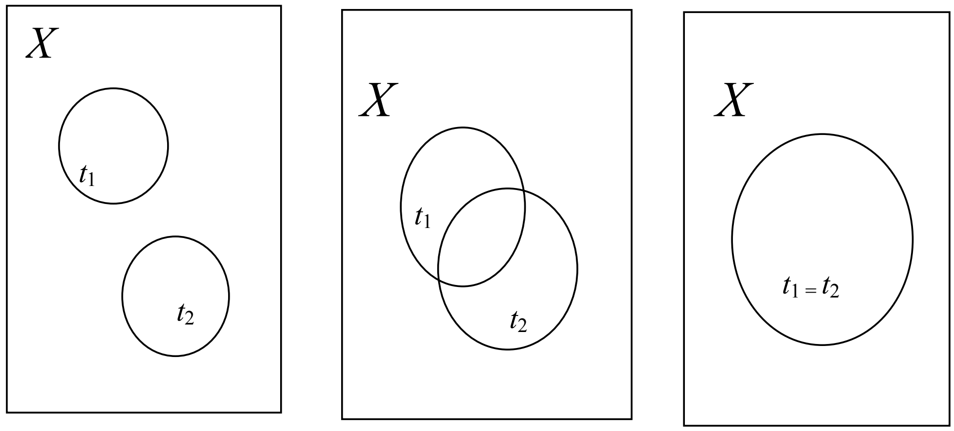
As far as the spillover effects of R&D are concerned, suppose that there are two firms, say 1 and 2, and indicate by β the spillover coefficient. We assume that the spillover coefficient depends upon the technological profiles of firms 1 and 2, t_1 and t_2, according to the mapping $\beta\colon \mathcal{C} \times \mathcal{C} \rightarrow \Re_+$ defined as follows:

$$\beta(t_1, t_2) = \frac{\nu(t_1 \Delta t_2)}{\nu(t_1 \cup t_2)} \cdot \frac{\nu(t_1 \cap t_2)}{\nu(t_1 \cup t_2)} = (1 - d(t_1, t_2))\, d(t_1, t_2) \qquad (1)$$

where the second equality follows from the definition of cognitive distance metric. Clearly, $\beta(t_1, t_2)$ is an increasing function of the "size" of the common knowledge subset of firms 1 and 2 ($\nu(t_1 \cap t_2)/\nu(t_1 \cup t_2) = 1 - d(t_1, t_2)$) – which, according to Nooteboom (2000), ensures comprehensibility - and of the "size" of the knowledge set which is not common at both firms ($\nu(t_1 \Delta t_2)/\nu(t_1 \cup t_2) = d(t_1, t_2)$) – which ensures novelty (see Figure 1). Moreover, $\beta(t_1, t_2) = 0$ if $t_1 = t_2$ or $t_1 \cap t_2 = \emptyset$, while $\beta(t_1, t_2) > 0$ if $t_1 \cap t_2 \neq \emptyset$ and $t_1 \neq t_2$.

Figure 2 illustrates the logic of relation (1). This relation, which expresses the effectiveness of interfirm interaction as a function of the cognitive distance, should provide a rigorous foundation to the theory of "external economy of cognitive scope" as illustrated in Figure 1.

Figure 2 - Cognitive distance, knowledge spillovers and technological profiles



a: $d(t_1, t_2) = 1$, $\beta(t_1, t_2) = 0$
novelty but no comprehensability

b: $0 < d(t_1, t_2)$, $\beta(t_1, t_2) < 1$
novelty and comprehensability

c: $d(t_1, t_2) = 0$, $\beta(t_1, t_2) = 0$
comprehensability but no novelty

The following results will be useful in the ensuing sections.

Lemma 1. Under the stated assumptions function β: $C \times C \rightarrow [0,1]$ is continuous and has a maximum.

Proof. See Appendix.

4. The basic model

In this section the basic model is presented. It is a three-stage duopoly game in which in the first stage firms choose the technological profile, in the second stage they choose the level of R&D and in the third stage they play a Cournot quantity game. With respect to the existing literature on R&D games with spillovers (see Katsoulacos and Ulph, 1998; Kamien and Zang, 2000), our model endogenises the spillover coefficient β, by drawing on a full-fledged theory, well established both from the empirical and from the theoretical point of view, as discussed in Section 2.

Consider two firms, say 1 and 2, which produce a homogeneous good and face the inverse demand curve $p = A - q_1 - q_2$, with obvious meaning of symbols. We assumes that for firm i (i = 1, 2) the production costs are represented by the following marginal cost function: $c - (x_i + \beta(t)\ x_j)$, where $c > 0$ is the common marginal cost without R&D, x_i and x_j are the R&D levels of firms i and j, respectively. Coefficient $\beta(t)$ is the R&D spillover coefficient and it depends upon the technological profiles of firms 1 and 2, $t = (t_1, t_2)$. (Now set X is interpreted as the set of all technological profiles compatible with production of the homogeneous good). We assume that the coefficient $\beta(t)$ is determined according to relation (1) (or (2)). The R&D activity carried out by firm i has a cost of γx_i^2, with $\gamma > 0$. For the sake of simplicity, we assume that the choice of the technological profile is costless (see also Kamien and Zang, 2000).[viii] The profit function of firm i is therefore:

$$\Pi_i = (A - q_i - q_j - c + x_i + \beta(t)x_j)q_i - \gamma_i x_i^2, \qquad i, j = 1,2..$$

We shall look for subgame perfect equilibria and for the sake of simplicity we specialise to symmetric equilibria in stages two and three. The optimal (symmetric) level of production of firms at stage three is:[ix]

$$q^*(x,t) = \frac{A - c + x(1 + \beta(t))}{3} \qquad (2)$$

where x is the symmetric R&D level. Its optimal level is:

$$x^*(t) = \frac{A - c}{9\gamma - (1 + \beta(t))}, \qquad (3)$$

The profits of each firm when q^* and x^* are implemented are:

$$\Pi^* = \gamma(9\gamma - 1)\left(\frac{A - c}{9\gamma - (1 + \beta(t))}\right)^2. \qquad (5)$$

If we adopt the technology representation introduced in the preceding section, then by Lemma 1 the coefficient β(t) has a maximum $t^* = (t_1^*, t_2^*) \in \mathcal{C} \times \mathcal{C}$. From (2), (3) and (4) it is obvious that the triplet (q^*, x^*, t^*) is a subgame perfect equilibrium, where $q^* = q^*(x^*, t^*) = \frac{A - c + x^*(1+\beta(t^*))}{3}$ and $x^* = x^*(t^*) = \frac{A-c}{9\gamma - (1+\beta(t^*))}$. Hence, we have proven:

Proposition 1. Under the stated assumptions the three stage duopoly game has a symmetric subgame perfect equilibrium.

The proof of the following fact follows immediately from relations (1) and (4).

Fact 1. If (q^*, x^*, t^*) is a symmetric subgame perfect equilibrium, then $t_1^* \neq t_2^*$ and $t_1^* \cap t_2^* \neq \varnothing$.

Fact 1 confirms the theoretical and empirical findings pointed out in Sections 2, according to which successful spillover excludes technological sameness (i.e. $t_1^* = t_2^*$) and technological dissimilarity (i.e. $t_1^* \cap t_2^* = \varnothing$).

5. Technological profiles, spillovers and R&D localisation

In this section, the model developed in the preceding section is applied to provide a rigorous explanation of the technology based theory of localisation of R&D of MNEs as indicated in Section 2.

Suppose again that there are two firms, say 1 and 2, which have to decide not only their technological profiles but also the geographical localisation of their R&D. Suppose that as for their technological profiles they can choose any element in the set $\mathcal{C}$ and as for their geographical localisation they can choose any point in the compact metric space (I, d_I), where d_I is a metric on I. The last assumption is very reasonable from the empirical point of view.[x]

Now we assume that the spillover coefficient depends not only upon the "cognitive distance" but also on the geographical distance between the two firms according to the function β: $\mathcal{C}^2 \times I^2 \rightarrow \Re_+$ defined as follows:

$$\beta(t,l) = \frac{\nu(t_1 \Delta t_2)}{\nu(t_1 \cup t_2)} \cdot \frac{\nu(t_1 \cap t_2)}{\nu(t_1 \cup t_2)} \cdot \max[0, \delta - d(l_1, l_2)] \tag{5}$$

where δ is a positive number. The spillover coefficient now depends inversely also upon the geographical distance between the two firms: given the cognitive distance, it is maximum when the two firms choose the same place (co-localise), it is minimum (zero) when the two firms choose a distance greater or equal to δ.

The game is the same as the three-stage game introduced in the preceding section, with the exception that now in the first stage firms choose their technological profile and their geographical localisation. Under the same assumptions concerning the demand and cost functions we have that the expressions (2), (3) and (4) still hold true except that now the spillover coefficient is β(*t*, *l*) rather than β(*t*).

In particular, profits when firms choose the optimal level of production and R&D are:

$$\Pi^* = \gamma(9\gamma - 1)\left(\frac{A - c}{9\gamma - (1 + \beta(t,l))}\right)^2. \tag{6}$$

Lemma 2. Under the stated assumptions, the function β: $\mathcal{C}^2 \times I^2 \rightarrow \Re$ defined by (5) is continuous. Moreover, it has a maximum

Proof. See Appendix.

From Lemma 2, take the maximum $(t^*, l^*) \in \mathcal{C}^2 \times I^2$. Clearly, from (6), the configuration (q^*, x^*, t^*, l^*) is a subgame perfect equilibrium, where $q^* = q^*(x^*, t^*, l^*) = \frac{A - c + x^*(1 + \beta(t^*, l^*))}{3}$ and $x^* = x^*(t^*, l^*) = \frac{A - c}{9\gamma - (1 + \beta(t^*, l^*))}$. Hence, we have proven:

Proposition 2. Under the stated assumptions the three-stage duopoly game has a symmetric subgame perfect equilibrium.

The following fact can be easily proven as Fact 1 before.

Fact 2. If (q*, x*, t*, l*) is a subgame perfect equilibrium, then $t_1^* \neq t_2^*$, $t_1^* \cap t_2^* \neq \emptyset$ and $l_1^* = l_2^*$.

Fact 2 confirms the theoretical and empirical findings pointed out in Sections 2, according to which successful spillovers require geographical co-localisation (i.e. $l_1^* = l_2^*$) and exclude technological sameness (i.e. $t_1^* = t_2^*$) and technological dissimilarity (i.e. $t_1^* \cap t_2^* = \emptyset$).

As a final remark, we want to point out that the extension of the game analysed in this section to the case in which there are more than two firms requires to tackle explicitly with asymmetric equilibria in the second and third stage, unless very restrictive assumptions from the empirical point of view are adopted as far as the relationship between the technological profiles and the spillover coefficient is concerned. The study of this case will be object of future research.

6. Conclusions

Empirical evidence has shown the growing significance of inter-firm network in the development of knowlegde as a result of the complex nature of technology in the current paradigm. In fact, a competitive market performance requires firms to "know more than they do" (Brusoni et al. 2001) since the production of successful output calls for a greater variety of related technological expertises for the sake of knowledge development. To cope with this situation, firms need to outsource new knowledge from complementary technological sources and absorb it into their technological portfolio. Regardless of their shape (STPs, geographical clusters, etc.), inter-firm networks are greatly affected by the cognitive distance between the corporate partners, as suggested by the empirical and theoretical literature. Different degrees of cognitive distance imply different extents of novelty and comprehensibility corporate interactions can generate. Following Nooteboom theory of "external economy of cognitive scope" it is possible to identify an optimal degree of cognitive distance, which allows the generation of non-redudant novel knowledge.

On the grounds of this theoretical argument, and building upon a previuos work by Granstrand (1994), we provide a formalisation of the concepts of technological profile, cognitive distance and its effect on knowledge spillovers. In turn, drawing on this formalisation we construct a three-stage non-cooperative R&D game with knowledge spillovers and choice of technological profiles. The model goes a step further the current literature as it endogenises the spillover coefficient on the basis a full-fledged theory of knowledge outsourcing. Furthermore, this game theoretical model is used to explain a simple pattern of corporate decisions of R&D localisation

Appendix

Proof of Lemma 1. By the properties of measure μ, it is finite. By the Radon-Nikodym Theorem (see e.g. Royden, 1988, 276), since measure ν is absolutely continuous with respect to μ, there exists an (unique and non-negative) integrable function *f* such that $\nu(E) = \int_E f d\mu$ for each $E \in \mathcal{B}$.Therefore, the spillover coefficient can be rewritten as:

$$\beta(t_1, t_2) = \frac{\int_{t_1 \Delta t_2} f d\mu}{\int_{t_1 \cup t_2} f d\mu} \frac{\int_{t_1 \cap t_2} f d\mu}{\int_{t_1 \cup t_2} f d\mu}. \quad \text{(A1)}$$

Any sequence of sets in $\mathcal{C} \times \mathcal{C}$ can be represented by a sequence of characteristic functions. Thus, from (A1) and from the Lebesgue Dominated Converging Theorem (see e.g. Royden, 1988, 91) continuity of β follows immediately.

Let us now endow set $\mathcal{C}$ with the Hausdorff metric topology, τ_H. Then, by the compactness of space (X, τ), space $(\mathcal{C}, \tau_H)$ is compact (see e.g. Castaing and Valadier, 1977, 41). Hence $(\mathcal{C} \times \mathcal{C}, \tau_H')$ is compact as well, where τ_H' is the product topology. The existence of a maximum follows immediately from continuity of β and from the compactness of $(\mathcal{C} \times \mathcal{C}, \tau_H')$.

Proof of Lemma 2. Write the coefficient β as follows: $\beta(t, l) = h(t) \cdot g(l)$, with obvious meaning of symbols. Function h is continuous with respect to t (see Lemma 1), moreover, function g is continuous with respect to l (trivial). Function β is the product of two functions which are continuous with respect to their variables, hence it is continuous with respect to either variables.

The space $(\mathcal{C}, \tau_H)$ is compact (see Proof of Lemma 1), space (I, d_I) is compact by assumption, hence space $(\mathcal{C}^2 \times I^2, \tau_{Hd})$ is compact as well, where τ_{Hd} is the product topology. The existence of a maximum follows immediately.

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[i] Following Nelson and Winter (1982), knowledge is here understood as the result of two components: a *public* and *codified* component (e.g. blueprints, books, etc.) and of a *private* and *tacit* component arising from an incremental and path-dependent learning process.

[ii] Following the resource-based view of the firm, the learning process encompassed in the development of new knowledge allows firms to exploit the potential of the new innovation in the future corporate R&D activity.

[iii] Following Nooteboom (2001), we define "cognition" in terms of "cognitive categories that are developed in interaction with the physical and social environment [which form] our perceptions, interpretations and evaluations" (*Ibid*., 3). In our analysis cognition is understood in terms of corporate technological profile. Thus, "cognitive distance" refers to the "distance" between corporate technological profiles as defined in section 3.

[iv] Co-location refers to the co-presence of R&D activity of two (or more) firms in the same territorial space.

[v] Co-specialisation refers to the co-presence of partners' technological expertise in the same technological sectors.

[vi] It is worth emphasizing that we restrict the choice of technological profiles to the closed subsets of X. This is a technical assumption which should have no substantial economic implications.

[vii] For a critical view of the set-theoretic and measure-theoretic representation of knowledge see Granstrand (1994, 216). For applications of knowledge sets to economics along the lines here adopted see Olsson (2000) and Garicano (2000).

[viii] It is possible to allow that the choice of the technological profile affects the marginal cost and it yields a fixed cost. Under assumptions comparable with those adopted in this paper, it is still possible to prove the existence of a subgame perfect equilibrium. However, in this first attempt we prefer to maintain the analysis as simple as possible.

[ix] We are well aware that optimising behaviour is not tenable from the empirical point of view, and we adopt it just for the sake of simplicity. However, once alternative behaviour (e.g. "satisficing") should be properly formalised, we believe that our results will still hold true.

[x] For example, the reader can suppose that $I = \{x \in \Re^3 | \, \|x\| = 6{,}378 \text{ km}\}$, where $\|\cdot\|$ denotes the norm operator. In this case, I can be interpreted as the set of points on the earth.