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the role of relational research capacity

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Abstract

Evolutionary theories of technological change and industrial dynamics give primary importance to interaction between heterogeneous agents, endowed with complementary assets and competencies. Accordingly, support to co-operative R&D is central to technology policy, as a mean for increasing system connectivity, triggering virtuous cycles of learning and promoting variety. The paper investigates the "chemistry of technological co-operation", relating its effectiveness and results to the partners' *relational research capacity*, i.e. their ability to evaluate, integrate, process and exploit knowledge flows generated by the interaction.
A functional specification for the relational research capacity is proposed and its properties are investigated. The formal analysis works as a guideline for the statement of research hypothesis related to the effectiveness of co-operative R&D programmes, to be tested on empirical grounds.

Keywords:

Technological co-operation, Innovation, absorptive capacity, competence integration

JEL:

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1- Introduction*

The paper deals with the issue of support to R&D co-operation and effectiveness of co-operative programmes, adopting an evolutionary perspective. The first section examines the relationship between the conceptualisation of the innovation process and technology policy prescriptions, by comparing the neoclassical and evolutionary approaches. The departure from the neoclassical concept of technology as information leads to review the orthodox concerns about appropriability and market failures. Evolutionary theories give primary importance to dynamic processes, knowledge content of technology and interaction between heterogeneous agents, endowed with complementary assets and competencies.

Accordingly, support to co-operative R&D is central to technology policy, since it increases system connectivity and promotes variety. Co-operative R&D is firstly a tool for facilitating the working of evolutionary mechanisms and virtuous cycles of learning. However, co-operative policies must deal with the evolutionary trade-off between exploitation and exploration, i.e. on the one hand policies should promote the clustering of related competencies in order to progress along established technological trajectories, and on the other they should support co-operation between heterogeneous actors in order to foster variety creation.

The paper explores the mechanisms of a related trade-off, that more closely concerns the degree to which joint R&D investment produces knowledge and gives rise to learning advantages: the trade-off between proximity and similarity of competencies.

The second part of the paper investigates the concept of *relational research capacity*, i.e. the ability to evaluate, process and exploit knowledge flows generated by R&D interaction. The main assumption is that the effectiveness of learning by interacting with technological partners depends on the level and nature of firms' knowledge base, on partners' cognitive distance, and on the knowledge features of the investigated technological field.
A functional specification for the relational research capacity is proposed and its properties are investigated. The formal analysis works as a guideline for stating hypothesis concerning the "chemistry" of technological co-operation, that are to be tested on empirical grounds.

EU technology policy represents an extremely interesting domain for the application of the theoretical analysis. In fact, support to co-operative R&D plays a central role in the European policy. The EUREKA Program and the latest Framework Programs promote a "connectivity-diversity" strategy, emphasising the need for strengthening the connectivity of the European innovation system, while promoting a certain degree of technological variety.

The evaluation of these policies requires a thorough understanding of the "chemistry" of technological co-operation. Further empirical research is needed to prove that the

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concept of relational research capacity is a valuable tool for assessing the consistency and effectiveness of co-operative strategies. Accordingly, this paper represents a step towards the development of a more general framework for the evaluation of co-operative technology policy.

2- Policy implications of neoclassical and evolutionary theorising about technological change

The theoretical analysis of technology and innovation processes and the planning of technology policy interventions are strictly related. Even though the contrast between the theory and the practice of policy might appear acute to any observer of the policy-making process (Metcalfe, 1995a), it is hard to question that different views of the economic process lead to different rationales and priorities in the agenda of the policy maker.

Indeed, the impact of the theory of innovation on technology policy has been remarkable since the post-war period. The most frequently cited example is that of the linear model of technological change, that has drawn attention to the critical role of basic research in the innovation chain and to the need for promoting or subsidising the generation and diffusion of generic knowledge:

"Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realm of science [..] A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill.*"*[1]

The linear approach owes much to the neoclassical theorising about technological change. The traditional analysis of the innovation process is conducted within an Arrow-Debreu framework: economic agents maximise the present value of some kind of utility (or profit) function, given some exogenous constraint and perfect information about the production and innovation possibility frontier. Therefore, innovative agents choose how much to invest in R&D by equating marginal costs and marginal benefits, which are calculated by efficiently using all available information. There is no room for concepts such as competencies or agent specific skills, since agents are assumed to be homogeneous. The firm is treated as a "black box", whose internal workings and structure can be ignored.

In neoclassical growth models, the process of technological change is observable mainly by its results, i.e. changes in the nature of inputs, variation of the production function or the "Solow residual" (Lipsey, 1998)[2].

The microeconomic contributions which deal with the process of technological change conceive the Schumpeterian trilogy (invention, innovation, diffusion) as a

[1] Bush V. (1945, repr.1980*), Science – the Endless Frontier. A Report to the President on a Program for Postwar Scientific Research*, Arno Press, New York, p. 19

[2] According to Vonortas (1997), the strong assumption about the unidirectional progression of events has mistakenly directed attention to the effects of exogenous "technology shocks", which are indeed not very predictable. Therefore, by defining basic research a necessary first step to the development of commercially relevant technology, the linear model essentially randomises the latter as well.

unidirectional and sequential process. The generation of new ideas is the first step of technological change, followed by design, engineering development, testing and diffusion across the market (Stoneman, 1987).

Technology is viewed as *information* (Nelson, 1959; Arrow, 1962; Stoneman and Vickers, 1988), which is produced like any other commodity by maximising agents in a competitive market. Implicit in this approach is the view that technological information is *generic, codified, accessible at no cost* and *context independent* (Smith, 1996). Such conceptualisation of technology emphasises its public good characteristics, which are the cause of market failures.

According to the neoclassical perspective, market failures constitute the rationale for public intervention and technology policy is mainly guided by such concern. There is a need for public intervention because rational agents underinvest in research, due to a wedge between social and private returns to such an investment. This wedge is caused by the nature of the technological production process, which is characterised by uncertainty, indivisibilities and externalities (Arrow, 1962), three generic sources of market failure.

In particular, it is the incomplete appropriability that reduces the private incentive to invest in R&D. The underlying assumption of this literature is that the costs of transmitting or absorbing information are very low, if compared with the costs of producing information. Therefore, the problem of externalities is very acute and concerns both the supply and the demand side. In fact, the private return to R&D investment is lower than the social return because of positive externalities to both competitors, who gain knowledge on a new product or process, and consumers, who benefit from cost reductions or widening of supply variety. Both externalities do not enter the calculation of private benefits and the competitive market does not reach the social optimal equilibrium. Moreover, as far as externalities to competitors are concerned, spillovers give rise to a "free-riding" problem: the incentive to invest in R&D is further reduced by the possibility of taking advantage from other investors' projects.

The policy maker intervention is guided by the principles which are stated by the theory of public goods and externalities, that highlights four main political measures: subsidies or taxes on private supply, public provision, definition of private property rights, internalisation (Stiglitz, 1986). All four approaches have been used in technology policy[3]. In this paper, however, we focus our attention on the last measure for solving the problem of externalities: internalisation through co-operative R&D.

Joint-ventures in the production of technology and innovative output can in principle overcome the free-rider problem, while being consistent with product market competition. Moreover, co-operative R&D, can solve the research duplication problem, which is a consequence of the race for patenting[4].

However, co-operation on the supply side might cause a welfare reduction for consumers. First of all, there is an obvious danger that co-operation in R&D will lead

[3] See Geroski (1995) and Mowery (1995) for a review.
[4] See Dasgupta and Stiglitz (1980a, 1980b), Wright (1983) and Dixit (1988) on the "common pool problem".

to anticompetitive collaboration in the product market, even when the agreement does not take the extreme form of a merger. Secondly, the research joint-venture can greatly diminish the incentive to innovate, because firms might realise that cost reductions cause a price fall and might therefore agree on slowing the pace of innovation in order to avoid such an event (Stoneman and Vickers, 1988).

Therefore, there is a trade-off between measures which solve the appropriability problem and the social need for a wide diffusion of information, that is to benefit final consumers. This trade-off captures the essence of neoclassical approach to technology policy: public intervention is directed to correct market failures, which are caused by inappropriate incentive mechanisms or imperfect distribution of information across agents. Co-operative R&D is a tool for correcting distortions caused by spillovers, i.e. by the very nature of technological information, that is hardly appropriable.

The shift to the evolutionary perspective brings about a shift in policy orientation. The evolutionary approach greatly departs from the neoclassical framework, by developing Schumpeter's analysis and assuming that process and change, rather than equilibrium and state, are the distinguishing characteristics of a capitalist economy (Schumpeter, 1911).

Change occurs as a sequence of variation and selection processes, which are fuelled by innovative activities. Change implies static inefficiencies, which do not represent the main rationale for public intervention. On the contrary, static inefficiencies are the necessary cost of sustaining variety and must be incurred if economic systems are to develop and evolve (Metcalfe, 1995a). The main concern of the policy maker is therefore that of ensuring a balance between "creative destruction" and "order", which is to be interpreted as co-ordination of the system rather than convergence to a centre of gravity, such as the Pareto optimum (Metcalfe, 1995b).

Accordingly, the evolutionary foundations of technology policy lies on a dynamic perspective and on a systemic view of innovation processes. In fact, the recent evolutionary contributions about innovation and technological change have brought to the centre of the theoretical debate the concepts of *system* and *interaction*. According to the evolutionary view, the linear model of technological change is inappropriate and misleading. Innovation is a process which involves flows of technology and information between the productive domain, the market and the research sector, and between heterogeneous agents, endowed with complementary assets and competencies. The locus of innovation is the network of public/private firms or research centres, rather than the single atomistic agent (Dodgson and Bessant, 1996).

This perspective is the starting point of two important strands of the evolutionary literature:

- **(a)** the microeonomic contributions building on the chain-linked model of Kline and Rosenberg (1986), that underlines chains of interaction and feedback paths between stages of the innovation process;
- **(b)** the innovation system analyses, that focus on the network of firms and institutions that contributes to the generation and diffusion of technology, at national (Freeman, 1987; Lundvall, 1988, 1992; Nelson, 1993), local (Perrin, 1991, Malerba, 1993) or sectoral level (Malerba and Orsenigo, 1995, 1997).

3 – Evolutionary foundations of technology policy

3.1 - Interaction as unit of analysis of the innovation process

The distinguishing feature of the evolutionary literature about innovation policy is the focus on interaction and learning: the innovative performance of a system does not depend on the action of single organisations, such as firms or research centres, but rather on how those units interact and on the institutional framework, shaped by public action and norms (Johnson, 1997).

Learning by interacting, both inside and outside the firm, is one of the main sources of knowledge in the modern economy[5]. There is room for learning because interaction occurs between heterogeneous agents, who hold specific competencies and whose behaviour is guided by routines, i.e. procedures that are deemed appropriate and effective in the settings where they are invoked (Nelson and Winter, 1982).

The term competence refers to a set of problem solving procedures, technical skills, understanding of demand and users' requirements, mastery of technology. However, those abilities and skills characterise both the people working in the organisation and the organisation itself. In this sense, competence may be related to the notion of intangible assets and the knowledge dimension of the enterprise (Dosi and Malerba, 1996). Knowledge creation is a process that goes beyond the individual level, as organisations can learn independently of each specific individual. Competencies are the result of a learning process which is cumulative, path-dependent and firm specific.

Moreover, the most strategic component of those "assets" is tacit. This implies that competencies are highly appropriable and difficult to transfer across firms (Winter, 1987)[6].

The differences in the competencies of the firms represent the potential engine of a learning economy, since they may give rise to relational advantages. The knowledge exchange that makes a research alliance unique could not be represented within the neoclassical framework of homogenous agents, since it is heterogeneity that gives the chance of combining complementary assets or competencies. Interaction between heterogeneous agents is a key evolutionary mechanism and may imply both creation of new varieties and selection of existing skills and knowledge.

3.2 - Technology as *knowledge*

The evolutionary theory develops a concept of technology which greatly differs from the neoclassical one. Technology is viewed as *knowledge*, rather than information. It certainly includes pieces of information, i.e. axiomatic propositions, codifiable knowledge, but it also involves knowledge that is tacit, "sticky", complex and difficult to codify (Nelson and Winter, 1982).

[5] According to Lundvall (1994), the modern economy is to be defined as a "learning economy", because knowledge is the most strategic resource and learning the most important process.

[6] According to Malerba and Orsenigo (1998), competencies can be interpreted as the "meta-structure" that allows to combine and integrate the codified and tacit parts of the whole stock of knowledge, and enables the agent to apply the knowledge to specific contexts and domains.

An important component of technological knowledge is the set of languages, codes of communications that are embodied in routines and are used to process external knowledge. In this sense, there is an interaction between explicit and tacit knowledge: exploitation of explicit knowledge generally requires tacit skills (Gjerding, 1998).

This aspect is crucial in the case of technological alliances, when different organisational languages and codes are to meet in order to transfer tacit knowledge. The exchange of tacit knowledge, which cannot be transferred in an arm-length fashion, may represent the main reason for setting R&D joint ventures agreements. Learning from technological partners involves mechanisms that are also important for the absorption of spillovers: evaluation of external knowledge through the organisation's codes, exploitation through the organisation's competencies. Therefore, the logic of the analysis that has been proposed with reference to learning from spillovers may be employed when referring to technological collaboration.

A very significant issue is that of *absorptive capacity*, that is strictly related to the evolutionary conceptualisation of technology as knowledge. Contrarily to the neoclassical hypothesis, costs of transmission and reception of technology may be significant, due to the intertwining of knowledge and competencies.

3.3 - Spillovers and absorptive capacity: the model of Cohen and Levinthal (1989)

The recent theoretical and empirical literature on innovation has paid much attention to spillovers. Three types of spillovers have been identified (Griliches and Mairesse, 1984): pecuniary spillovers (R&D intensive inputs and outputs are not priced in their full value), knowledge spillovers (scientific and technological knowledge is transferred from one agent to another without adequate compensation), network spillovers (the successful implementation and economic value of a new technology strongly depends on other complementary technologies).

We focus here on *knowledge spillovers*, that may be horizontal (knowledge flows between competitors) or vertical (knowledge flows between agents in different industries). The evolutionary assumption is that such flows are not easily and freely appropriable by firms. Rather, their absorption and exploitation depends on firms' prior related knowledge and competencies. Cohen and Levinthal (1989, 1990, 1994), define the *absorptive capacity* as the ability to recognise the value of new, external information, assimilate it, and apply it to commercial ends. This ability is a function of the past and current investments in R&D, that favoured an internal process of learning[7]. This analysis emphasises a dual role of R&D, that generates new knowledge and develops the firm's absorptive capacity.

Cohen and Levinthal (1989) model the flow of technological and scientific knowledge (z_i) that adds to the firm's stock of knowledge and is positively related to the firm's gross earnings. The authors distinguish two main sources of knowledge, an internal one, resulting from in-house investments in R&D, and an external one, resulting from spillovers:

[7] See Malerba (1992) for a taxonomy of learning, inside and outside the firm.

$z_i = M_i + \gamma_i (\theta\, \Sigma_{j\neq i} M_j + T)$ $\quad 0\leq\theta\leq 1\ ;\ 0\leq\gamma_i\leq 1$

where M_i is the firm's investment in R&D, $\Sigma_{j\neq i} M_j$ is the investment in R&D by the other firms of the industry (or of the technological area), θ is the degree of intra-industry spillovers, and T is the level of the extra-industry knowledge, generated, for example, by public R&D laboratories or Universities. The term $(\theta\, \Sigma_{j\neq i} M_j + T)$ represents the pool of external knowledge that the firm can access.

However, the key variable of the model is γ_i, that represents firm's absorptive capacity. Cohen and Levinthal assume that γ_i depends on two parameters, M_i (in-house R&D) and β, that reflects the degree of complexity of external knowledge. The more complex, less codifiable, more distant from the firm's codes and routines, less tailored to the firm's needs is knowledge, the higher is β. The properties of $\gamma_i (M_i, \beta)$ are captured by the signs of the partial derivatives:

- $[\delta \gamma_i (M_i, \beta)/ \delta M_i] > 0 \qquad [\delta^2 \gamma_i (M_i, \beta)/ \delta M_i\, \delta M_i] < 0$

  firm's in-house R&D increases its absorptive capacity, though at a decreasing rate;
- $[\delta \gamma_i (M_i, \beta)/ \delta \beta] < 0$

  given the level of firm's R&D, an increase in the complexity of external knowledge reduces the firm's absorptive capacity;
- $[\delta \gamma_i (M_i, \beta)/ \delta M_i \delta\beta] > 0$

  the larger is β, the greater is the *marginal* impact of in-house R&D on absorptive capacity[8].

Llerena and Oltra (1999) propose an explicit function for γ_i that exhibits the above properties:

$$\gamma_i = 1 - 2\frac{\beta}{\sqrt{\underline{R}_{it}}}$$

where $0 < \beta < 1$, and the firm's research level, $\underline{R}_{it}$, is a weighted average of past research level and current R&D expenditures:

$$\underline{R}_{it} = \alpha_R R_{i,t-1} + (1-\alpha_R) R_{it} \qquad 0 < \alpha_R < 1$$

In particular,

$$\frac{\partial^2 \gamma_i}{\partial \underline{R}_{it} \partial\beta} = \frac{1}{\underline{R}_{it}\sqrt{\underline{R}_{it}}} \geq 0$$

The variable β therefore reflects how much critical is R&D to the maintenance of absorptive capacity. We can expect, for example, a larger impact of R&D on absorptive capacity in science-based sectors, where external knowledge is generic and highly cumulative, i.e. firms need to understand each step of the scientific or technological development in order to get an efficient use of it.

[8] Cohen and Levinthal (1989) also study the properties of the symmetric Nash equilibrium in R&D levels, when n firms are assumed to compete *à la* Cournot. This equilibrium value, M*, appears to be positively correlated with β. As β increases, the firm has greater incentive to conduct R&D, because R&D becomes more critical to assimilate external knowledge (competitors' spillovers and extra-industry knowledge).

Cohen and Levinthal's analysis underlines the dependence of external learning from investments in processes of internal learning. What the neoclassical perspective views as a source of market failure, i.e. positive externalities, may indeed represent an incentive to invest more resources in internal processes of learning, such as R&D activities. In fact, firm level R&D will be encouraged when spillovers from other firms are large, because increasing R&D will put each firm in a better position to learn from its rivals and appropriate rewards from their work (Hall, 1994).

Indeed, the concept of market failure is not consistent with the evolutionary approach, since it implies a departure from a static equilibrium. The evolutionary view rather refers to systemic or evolutionary failures, i.e. failures in the mechanisms underlying variation and selection processes. Learning and interaction are essential engines of evolutionary processes and the policy maker role is to favour the working of those mechanisms, to encourage virtuous cycles of learning.

3.4 - Evolutionary failures and technology policy: the role of co-operative R&D

The rationale of public action is intrinsically related to the identification of failures within the decentralised market. Evolutionary contributions try to make operational the dynamic and systemic approach by emphasising traps and trade-offs that hamper the working of evolutionary mechanisms. These failures may, for example, prevent the occurrence of variation and selection processes or unbalance them. With reference to Metcalfe's notion of *evolutionary order* (Metcalfe, 1995b), systemic failures imply a lack of co-ordination in the development process of the system. The concepts of learning and interaction as outlined above are crucial for the understanding of those failures.

Malerba (1997) outlines a typology of evolutionary failures and trade-offs that may work as a reference for policy action:

(1) *learning failures*: firms or industries may not be able to learn rapidly and effectively, and may be locked into existing technologies. Lock-in problems are therefore interpreted as a result of slow or ineffective learning;

(2) *exploration/exploitation* and *variety/selection trade-off*: industries may be characterised by an excess of exploration, i.e. by an excess of variety generation with weak selection processes, or by an excess of exploitation, i.e. tough selection with little variety generation;

(3) *appropriability traps*: too stringent appropriability may greatly limit the diffusion of advanced technological knowledge and prevent the development of differentiated technological capabilities within an industry;

(4) *dynamic complementarities failures*: sustained innovative activities take place through interaction between complementary technologies, functions and actors. When the nodes of the system are poorly connected, virtuous cycles of learning and innovation cannot take place.

Effective interaction plays a key role for the overcoming of the failures above: learning by interacting is one of the main sources of technological knowledge and it is the essential condition for promoting dynamic complementarities. The main policy implication of the evolutionary emphasis on interaction, technological knowledge and learning is the need for the policy maker to enhance the connectivity of the system in order to exploit and expand its knowledge base and its capacity to learn (Lundvall and Borrás, 1997). As Dodgson and Bessant (1996) state, innovation policy's principal aim is to facilitate the interaction between multiple actors.

The role of co-operative R&D goes much beyond that of internalising externalities. Support to R&D networks triggers virtuous cycles of learning. Moreover, co-operation may be the only way for addressing complex scientific and technological issues, that cannot be managed within a single unit characterised by specific capabilities (Gjerding, 1998). Therefore, co-operation is firstly a way for pooling capabilities and learning from each other's codified and tacit knowledge. The learning process within an innovation network follows from a constant exchange of knowledge, as well as the collective production and exploitation of new knowledge, based on mutual trust.

However, the exchange of tacit knowledge requires higher elements of trust and cultural understanding (Lundvall and Borrás, 1997). Interaction by itself does not necessarily imply an effective exchange of tacit knowledge and mutual learning. The effectiveness of such a process greatly depends on the investment in relation-specific assets (Dyer and Singh, 1997) and on the characteristics of the agents involved.

The literature on R&D networks and innovative milieu underlines the importance of geographical proximity, since firms and institutions located in a specific setting are expected to have shared interests and understandings (e.g. Saxenian, 1994).

The aim of this paper is that of emphasising the significance of another kind of proximity for the effectiveness of R&D co-operation, “cognitive proximity”. The analysis follows the main assumption that the effectiveness of co-operative R&D, in terms of knowledge production, greatly depends on the technological, "cognitive" characteristics of partners, that determine firms' absorptive and integrative capacity in relation with that specific alliance.

Moreover, the ability of the firm to get economically useful knowledge out of a R&D investment depends on another type of distance: the distance between the firm’s technological core competencies and the specific technological field to which the investment refers.

In both cases there is a trade off- between exploitation and exploration, with regards to the partners’ competencies and the technological space.

Co-operative R&D programmes, that meet a need for connectivity, need to be evaluated by consistently taking into account the evolutionary analysis of technological knowledge and spillovers' effects. For those programmes to be effective, the firms must be able to evaluate and exploit the tacit knowledge that belongs to partners or that is generated during the interaction itself. In fact, knowledge generated by interacting in technological projects might be only partially appropriated by partners. In the same way as internal codes and languages and cumulated capabilities are important for exploiting spillovers, i.e. results of rivals' R&D that become publicly available, the competence base of the firm can be assumed as affecting the degree to which the firm benefits from R&D interaction. Policy design and evaluation need to take into account these factors, that may result in unforeseen constraints or opportunities.

The following section tackles the issue of knowledge production by R&D interaction. The contribution of co-operative R&D to a firm's knowledge base and innovativeness is related to the factors affecting the "chemistry" of technological co-operation.

4 - Knowledge production by R&D interaction: the issue of relational research capacity

Following the main lines of evolutionary theory, the analysis moves from the basic assumption that economic agents are heterogeneous and that technological interaction is one of the main sources of knowledge and innovativeness.

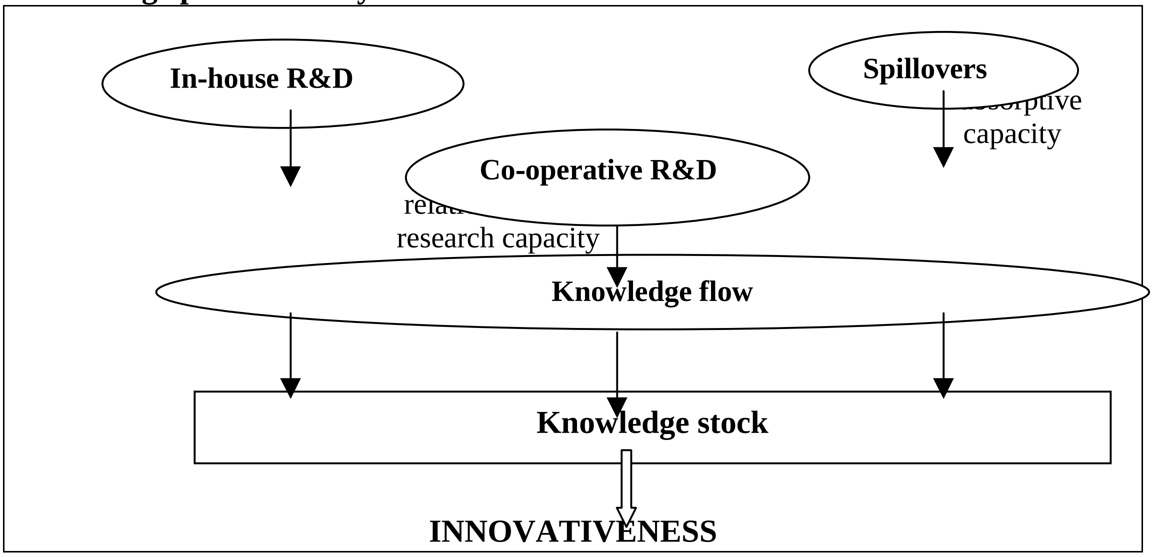
Each economic agent is endowed with a knowledge stock that results from past and current investment in internal research activities, co-operative ventures and absorption of spillovers. The knowledge stock (Z) in turns determines the probability of the firm to innovate (Figure 1). Innovativeness directly affects firm's productivity (A) and indirectly the firm's economic performance, as measured, for example, by profits (Π). Feedbacks run from the evaluation of performances to R&D investment rules, that may themselves change over time as a matter of evaluation.

Figure 1

In-house R&D
Co-operative R&D $\longrightarrow$ Z $\longrightarrow$ Prob (Innovation) $\longrightarrow$ Innovation $\longrightarrow$ A $\longrightarrow$ Π
Spillovers

In this paper however we focus only on the first step of this linked chain: the generation of knowledge by R&D investment, in particular by R&D interaction (Figure 2).

Figure 2
Knowledge production by R&D interaction



We assume that the knowledge stock of firm *i* at time *t* (Z_{it}) results from a process of accumulation and depreciation:

$$Z_{it} = (1-\delta_z)\, Z_{i,\,t-1} + z_{it}$$

where δ_z is the depreciation rate and z_{it} is the flow of knowledge that adds to the stock at time t.

This representation is consistent with the evolutionary approach: technological knowledge is the output of a cumulative process but may depreciate because of obsolescence and forgetting.
With reference to Cohen and Levinthal (1989) model, co-operative R&D (CR_i) can be viewed as an additional source of knowledge for the firm. Therefore, the knowledge flow at time t is related to three different sources[9]:

$$z_{it} = R_{it} + \gamma_i\, (\theta\, \Sigma_{j\neq i}\, R_{jt} + T_t) + \Sigma_s\, \alpha_{ijs}\, CR_{ist}$$

R_{it} is firm's in-house R&D, ($\theta\, \Sigma_{j\neq i}\, R_{jt} + T_t$) is the spillover term and γ_i is the absorptive capacity as traditionally defined. CR_{ist} is the investment of firm *i* at time *t* in co-operative R&D projects in field *s*, and α_{ijs} represents the degree to which the co-operative effort with the partner(s) *j* in field *s* translates into valuable knowledge for the firm *i*, i.e. the "relational research capacity". Valuable knowledge is to be interpreted as knowledge that can be promptly translated into innovative ability, i.e. knowledge that increases the probability to innovate. This may imply the ability to "absorb" knowledge from technological partners, therefore an absorptive capacity in the sense of Cohen and Levinthal, but also the ability to "integrate" the firm's competencies with those of the partners. While absorption implies flows of knowledge between partners, the concept of "integration" is more related to the creation of novelty, of "non-redundant" knowledge. The distinction between integration and absorption is important, because a firm may take advantage from co-

[9] Other sources of learning, such as learning by doing, are here omitted. However, the "chemistry" of formal R&D co-operation mainly concerns economic agents that significantly invest in formal R&D. Therefore, the omission of informal R&D activities should not greatly underestimate knowledge production.

operative R&D even without significantly absorbing knowledge from the partners. Instead, valuable knowledge and innovative output may result from the integration of complementary skills and competencies, from the convergence of independent pieces of knowledge.

The two aspects are clearly related, and, at empirical level, hard to disentangle. Nevertheless, a theoretical distinction appears to be useful as a tool for relating the effectiveness of co-operation to the specificity of the technological field. The assumption we make here is that the degree to which the relational research capacity is affected by “absorptive” capacity and/or “integrative” capabilities depends on the features of the technological field being investigated. Some technological areas require partners’ cognitive proximity and reciprocal knowledge absorption, some other technological fields require the integration of diversified competencies.

The relationship between technological specificities and patterns of innovative activity has been investigated by the literature about “technological regimes” (Nelson e Winter, 1982 Winter, 1984; Dosi, 1988, Malerba and Orsenigo, 1990, 1993, 1997). Next section will focus on the dimensions of a technological regime that may affect the relative importance of “absorptive” and “integrative” capabilities within a technological partnership and will depict two polar cases that set the framework for the subsequent analysis.

4.1 – Relational capabilities and technological environment: *absorptive* and *integrative* case

The notion of “technological regime” provides a multi-dimensional description of the technological environment in which firms operate. Specific characteristics of technology, knowledge base and institutional framework are employed to explain patterns of firm behaviour and industrial evolution.

Malerba and Orsenigo (1990, 1993) characterise technological regimes in terms of *opportunity*, *appropriability* and c*umulativeness* conditions, and in terms of the *complexity of the knowledge base* (Table 1). We focus here on cumulativeness and nature of the knowledge base as the key features for assessing the relative importance of integrative and absorptive capabilities within a RJV.

Table 1
Technological regimes

Combination of:	Dimensions
Opportunity conditions Ease of innovating for any given amount of resources invested in research	Sources (internal/ external, embodied/ disembodied) Level (low/ high) Pervasiveness (low/ high)
Appropriability conditions Possibilities of protecting innovations from imitation and extracting profits from innovative activities	Level (low/ high) Means (patents, secrecy, control of complementary assets, etc.)
Cumulativeness Degree by which the generation of new knowledge builds upon current knowledge	Level (technological, individual, organisational)
Knowledge base Knowledge relevant for the innovative activities of an industry	Degree of tacitness Degree of complexity

Source: adapted from Malerba and Orsenigo (1993)

Cumulativeness at technological level is related to the specific features of the technologies and denotes learning processes characterised by increasing returns. A high level of cumulativeness favours specialisation of innovative activities along a technological trajectory and amplifies first movers' advantages.

The knowledge base may be characterised in terms of degree of tacitness/codification and complexity. The distinction between tacit and codified knowledge is closely related to the means of knowledge transmission. The more tacit is knowledge the less relevant and effective are formal means of knowledge exchange, and the more important becomes the sharing of common languages and codes, that result from formal training, informal learning and interactive experiences. The degree of complexity is related to the "composition" of knowledge and technologies. According to Malerba and Orsenigo (1993), complexity is to be defined in relation with two aspects. First, innovations may require the integration of different scientific disciples and technologies. Second, innovative activities may be fed by the contribution of a variety of competencies, concerning, for example, production processes and nature of markets. Greater complexity reflects in a growing need to command a multiplicity of technologies (von Tunzelmann, 1996; Patel and Pavitt, 1997).

We may relate the relative importance of absorptive and integrative capabilities to the characteristics of the technological environment and identify two polar cases.

We may refer to an *integrative case* when technology is highly systemic (i.e. technological advances in different fields are highly interdependent) and complex (i.e. there is a strong need to command diversified competencies and technologies), and knowledge critical to innovation is mainly codified or codifiable. In this case, it is the ability to match complementary skills and competencies, rather than building up a critical mass of knowledge in a specific area, that matters for the effectiveness of the partnership.

We may refer to an *absorptive case* when knowledge underpinning innovative activities is tacit to a significant extent, the degree of cumulativeness is high, favouring specialisation along a technological trajectory, and technological development is "specific" as opposed to "systemic", i.e. research can be conducted in a very specific field, with limited need for mastering complementary knowledge or setting the research within a system of interrelated fields. Co-operation in this environment requires sharing of tacit knowledge and a similar technological background, since today's innovativeness builds upon past research along a specific trajectory.

The technological environment represents the framework for analysing the way firms' specific variables enter the relational research capacity. In particular, technology characteristics in terms of cumulativeness, tacitness, complexity and structure of the knowledge base, i.e. whether we are close to the absorptive or integrative case, determine the way partners' cognitive distance affect the RJV's knowledge output.

Next section will focus on the determinants of the relational research capacity and introduce hypothesis about the way the technological environment might "shape" the trade-off related to partners' technological distance.

4.2 – Determinants of the relational research capacity

The relational research capacity represents the degree to which co-operative research with partner(s) *j* in field *s* translates into valuable knowledge for firm *i*.

$$\alpha_{ijs} = \alpha_{ijs} (\underline{R}_i (t) , \underline{CR}_i (t), \beta_{is} , d_{ij} , g_i , a_s , b_s)$$

Similarly to γ_i, the absorptive capacity term in Cohen and Levinthal's model, α_{ijs} is endogenous and depends first of all on the firm's research level, $\underline{R}_i$. Through internal R&D the firm develops its knowledge base and acquires "learning-to-learn" capabilities. The perpetual inventory method seems to be appropriate for the measurement of this variable. In fact, this approach assumes that R&D expenditures are accumulated into a knowledge stock and depreciation occurs (e.g. Griliches and Mairesse, 1984; Cuneo and Mairesse, 1984; Los and Verspagen, 1997) [10]. Assuming a fixed rate of depreciation, δ[11], the research level of firm i at time t is therefore measured as a weighted average of current and past in-house R&D investment:

$$\underline{R}_i(t) = \Sigma_\tau \, \omega_\tau \, R\,(t-\tau)$$

where $\omega_\tau = (1- \delta)^\tau$ is the geometrically declining weight .

We may also assume relational research capacity is positively correlated with the firm's co-operative R&D level ($\underline{CR}_i$), measured in accordance with the perpetual inventory method. Previous co-operative R&D experiences, in fact, besides adding to the firm's knowledge base, favours the development of relational skills, i.e. "learning-how-to-interact" capabilities, and specific relational competencies, such as the ability to co-ordinate and integrate in-house changes with developments brought about by partners.

[10] This method is consistent with the evolutionary interpretation of learning by searching. R&D investments build on a stock of knowledge that can be eroded by obsolescence or forgetting.
[11] A 15% rate of depreciation is commonly used.

Further, α_{ijs} is assumed to depend on the distance between the research area *s* and firm *i*'s technological core, as measured by β_{is}. We may assume that the ability to translate co-operative investment into exploitable knowledge is greater the closer is the research field to the firm's core.

The firm's research interests over different technological classes may be characterised according to two dimensions: intensity (in absolute and relative terms), and degree of diversification. The relative intensity is the criterion for identifying the firm's technological core, and consistently measuring β_{is}[12]. However, the degree of diversification, g_i , plays an important role in determining α_{ijs} as well. In fact, the range of technological competencies clearly affects the range of R&D alliances in which the firm may profitably engage. We may assume that the more diversified is the knowledge base the greater is the ability of the firm to integrate knowledge flows coming from heterogeneous sources and to "communicate" with technological partners whose core competencies do not greatly overlap those of the firm.

Different measures of technological diversification, based on the distribution of patents over technological classes, can be employed. For instance, the indicator can be based on the distribution of patents over a few macroclasses, when those classes have been attributed a weight that measures their relative importance in the firm's technological activity[13]. The Herfindhal index is commonly employed as a proxy of a firm's technological concentration:

$$H_i = \propto_k s_k^2$$

where s_k is the share of the firm's technological activity in the k technological class, as proxied, for example, by the share of the firm's patents in this class. Accordingly, the measure of diversification is given by:

$$g_i = 1- H_i$$

which is closer to unity the higher is the degree of technological diversification.

The degree to which CR_{ijs} effectively increases the firm's valuable knowledge also depends on the cognitive distance between the partners (d_{ij}). We may assume there is a trade-off between *proximity*, that makes the exchange of tacit knowledge easier, and *similarity* that narrows the scope for matching complementary skills. For example, a firm that invests a limited amount of resources in R&D or has little experience with the elaboration and exploitation of basic research can take great advantage from the co-operation with science-based firms, R&D centres or Universities, which give access to a pool of knowledge otherwise unavailable, but differences in languages, codes and routines represent a significant obstacle for the exchange of tacit knowledge. Even codified knowledge is difficult to be assimilated and processed if there is a lack of related in-built knowledge. A similar trade-off may occur when partners have very different technological experience and background. If they are experienced with research in "distant" technological classes, we may expect a great

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[12] More on this point in section 4.3.

[13] An example of such a weighted measure is given by :

$$g_i = \Sigma_k\, \omega_k\, x_k$$

where x_k=1 if the firm has patents in the k macroclass (x_k=0 otherwise), and ω_k is the ratio between the number of patents in the class k and the number of patents in the class j, where j is the "core" technological class of the firm, i.e. the most important class in the patent portfolio (if k=j, ω_k=1) (Boni, 1994).

scope for widening their technological base, but also difficulties in deepening their knowledge on technical issues that do not relate to their "core competencies".

As Nooteboom (1999) points out, for reciprocal learning to take place, partners should on the one hand have sufficient cognitive distance, i.e. possess different cognitive categories, in order to create “non-redundant” knowledge, but on the other hand they should be sufficiently close, in cognition and language, to enable meaningful communication.

The relevance and impact of the trade-off may however change depending on the features of the investigated technological field[14]. The technology-specific parameters a_s and b_s are aimed at binding the distance trade-off to the characterisation of the technological environment. The sign and the value of those parameters are assumed to vary over technological fields, so that the two polar cases outlined above can be identified. The sign of the parameters defines the proximity to the integrative or absorptive case, while their ratio captures the intensity of those cases’ distinctive features.

The *integrative case* is depicted by *positive* values of a_s and b_s. The more knowledge is codified (or codifiable), systemic and complex, the more emphasis is to be placed on the “integrative side” of the relational research capacity. The more important are those features the greater is the ratio a_s/b_s. Within this environment the trade-off proximity/similarity exhibits features that correspond to the intuitive idea of a balance between cognitive proximity and cognitive distance for the co-operation to be effective. When partners’ knowledge structures are very similar the learning output of co-operative R&D is very low. α_{ijs} increases with cognitive distance, up to a threshold, beyond which heterogeneity of research codes, techniques and interests reduces communicability.
The *absorptive case* is depicted by negative values of a_s and b_s. In this case, effective co-operation rests on great mutual understanding and sharing of tacit knowledge, and we may expect innovative output to be greatest when partners are very close in the cognitive space. The greater the ratio a_s/b_s (in absolute value), the more marked are the “absorptive” features, the more heterogeneity reduces the knowledge output of the R&D alliance.

Cognitive distance play a central role in determining the effectiveness of co-operative R&D in terms of knowledge production and innovation. Accordingly, the positioning of heterogeneous agents in the technological space, or their characterisation in terms of knowledge endowment, becomes a central issue.

4.3- Measures of cognitive distance

The question of measuring cognitive distance has been largely investigated in the empirical literature dealing with knowledge spillovers. In order to calculate intra-sector spillovers, Jaffe (1986, 1989), for example, locates firms in the “technological space”, using a vector (F) containing the number of patents per technology field:
$F = (f_1 \ldots f_k)$

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[14] See section 4.1.

where f_k is the fraction of the firm's research budget devoted to area k, proxied with the number of patents in the k technological class. The use of patents as proxies follows the assumption that the distribution of a firm's patents across the patent classes reflects the underlying distribution of research interests[15]. The measure of cognitive distance between firm i and firm j is given by:
$d_{ij} = 1 - P_{ij}$
where P_{ij} is a measure of proximity, or closeness, of the firms' patent distribution, and it is calculated as the angular separation or uncentered correlation of the patent vectors[16]:

$$P_{ij} = \frac{F_i F_j}{\|F_i\| \|F_j\|} = \frac{\sum_{k=1}^{K} f_{ik} f_{jk}}{\sqrt{\sum_{k=1}^{K} f_{ik}^2 \sum_{k=1}^{K} f_{jk}^2}}$$

P_{ij} is bounded between 0 and 1 and is closer to unity the greater the degree of overlap of the firms' research interests. Therefore, the closer is d_{ij} to unity the less similar are the knowledge structures of firms as proxied by their patent portfolios. This measure seems appropriate as a proxy of the cognitive distance between R&D partners, that should reflect different learning experiences, related to firms' specific research interests and investments[17].

The measurement of the distance between the research field and the firm's technological core (β_{is}) requires some proxy of knowledge relatedness and, of course, a measurable definition of technological core.

As far as the latter is concerned, an intuitive measure is given by the patents concentration in technological classes. The firm's technological core is then identified with the class/es in which the patenting share is highest. However, this measure may be strongly biased because of different patent-propensity across technologies. A high share of firm's patents in a technological class may result from the greater effectiveness of patents as an appropriability instrument in this class, relatively to other technological classes. Breschi et al. (1999) propose a criterion that takes into account the differences across classes in propensity to patent. The firm's shares of patents in various classes are calculated as the number of patents held by the firm in

[15] The usual drawbacks related to the use of patents as indicators of technological activity apply. In particular, patents measure codified knowledge, whereas a high proportion of firm-specific competencies is based on tacit knowledge (Patel and Pavitt, 1997). Moreover, the propensity to patent varies systematically across sizes of firm, types of inventor and technologies. Therefore, this indicator underestimates firms' research interest in low patent-propensity areas (e.g. computers and semiconductors) and overestimates research interest in high patent-propensity fields (e.g. chemicals) (Jaffe, 1989). Griliches et al. (1987) and Griliches (1990) address these issues in detail.
[16] The angular separation of the vectors is equal to the cosine of the angle between them. The measure of proximity is therefore related to the direction the patent vectors are pointing, but not necessarily to their length (Jaffe, 1989).
[17] Firms' knowledge base, as characterised by F, may be viewed as their technological DNA, which includes communication codes and determines their ability to relate with the environment. In this sense, co-operative projects work as enzymes that attract heterogeneous agents and the chemistry that results from the combination of their peculiar knowledge traits determines the knowledge output. Matching of very similar agents may lead to a deepening and sophistication of their current features, while matching of rather heterogeneous entities may enlarge their knowledge spectrum.

each class over total number of patents at the world level in that class. The class with the highest share is then labelled as the firm' s core[18].

The measure of knowledge relatedness should reflect the closeness of the firm's main research interest (i.e. the field to which the firm is mostly acquainted and the technology that it can master at best), with the area of the joint R&D investment. The choice of measuring the knowledge relatedness employing a narrow definition of the firm's technological core is questionable. It might be the case that the research field is distant from the firm's technological core, but it is close or overlaps some other fields that are still significant to the firm's technological activity. An alternative measure may therefore look at the distance between the research field and the closest "distinctive competence", where distinctiveness is defined in terms of resources devoted by the firm to the field and in terms of Revealed Technological Advantage (RTA)[19]. Another criterion is that of considering the distance between the research field and the closest technological class in the firm's patent vector, independently of the weight of this class in the patent portfolio. The choice of the narrowest definition is driven by the idea that what makes a significant difference for the relational research capacity is whether the investment concerns the field in which the firm has developed its core competencies, its most strategic research techniques and communication codes, its most critical tacit knowledge, or whether it concerns a field that does not refer or only partially refers to the firm's in-built technological culture.

Measures of knowledge relatedness that make use of patent classification codes have been proposed in the literature assessing spillovers impact. Verspagen and De Loo (1998), for example, construct a matrix of technology flows using patent citation rates and take the fraction of total technology output of sector i flowing as a spillover to sector j as an indicator of distance between i and j.

Breschi et al. (1999) propose an alternative measure of knowledge relatedness that is based on the co-occurrences of classification codes in patent documentation. The more similar is the pattern of co-occurrences of technological field i and j with all other fields, measured by vectors, the more related are i and j. The measure of relatedness is given, as in the case of d_{ij}, by the angular separation between the co-occurrences vectors.

If we adopt this approach, we need first to define the vector of co-occurences per technology field:

$C_i = (c_1 \ldots c_k)$

where c_k is the share of co-occurences of field i with field k, i.e. the share of the patents classified in field i that are classified in field k as well[20].

The measure of distance between firm i's technological core and technological field s is then given by:

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[18] The same authors however point to some drawbacks of this criterion. In particular, the weight of niche technologies may be overestimated. In fact, those technologies can host a relatively small number of firms and patents, so that innovators have high world shares, even if the R&D investment in those fields represents just a small part of their whole innovative effort.

[19] The RTA of firm i in field s is defined as firm i's share in total patenting in field s divided by the firm's share of total patenting in all fields. See Granstrand et al. (1997) for an application.

[20] The use of relative rather than absolute values is consistent with the need to avoid over-estimation of knowledge relatedness when large fields, in terms of patent applications, are involved.

$\beta_{is} = 1 - S_{is}$
where S_{is} is the angular separation between the co-occurences vectors, C_i and C_s :

$$S_{is} = \frac{C_i C_s}{\|C_i\| \|C_s\|} = \frac{\sum_{k=1}^{K} c_{ik} c_{sk}}{\sqrt{\sum_{k=1}^{K} c_{ik}^2 \sum_{k=1}^{K} c_{sk}^2}}$$

S_{is} is bounded between 0 and 1 and is closer to unity the more similar are the two fields in terms of their mutual relationship with all other fields[21].

The impact of the two typologies of technological distance (d_{ij} and β_{is}) on α recalls the trade-off between exploitation and exploration. At the firm level, this trade-off is mainly captured by β. When the firm engages in R&D along a well-known technological trajectory, the probability to innovate is higher but the increasing specialisation may decrease the capability to communicate effectively with distant partners, absorb their knowledge or integrate their competencies. When the firm enters technological trajectories that are less related to its core, the probability to innovate is lower, but the widening of its knowledge base may favour communication with agents at distance in the technological space and the management of innovation processes that require to mobilise a wider array of technological capabilities[22].

However, while the policy trade-off that evolutionary contributions generally underline (promote co-operation between "distant" agents or favour the clustering of similar competencies) concerns the "quality" of the output of co-operation, that affects the degree of variety within the economic system as a whole, the related trade-off proximity/similarity more specifically concerns the internal working of the co-operative venture. In other terms, the attention is focussed on the "quantity" of valuable knowledge that may be appropriated or generated by partners and on how this relates to their knowledge characteristics and to the technological environment.

4.4- A functional specification for the relational research capacity

The functional specification of α_{ijs} should capture the trade-off proximity/similarity and, at the same time, account for the dependence of relational research capacity on in-house and co-operative R&D and on β_{is}.

As far as the trade-off is concerned, a linear specification does not seem appropriate. In fact, we may expect in general α_{ijs} to be positively affected by an increase in the cognitive distance when partners are very close and the reverse when partners are already positioned at distance in the technological space (Figure 3).

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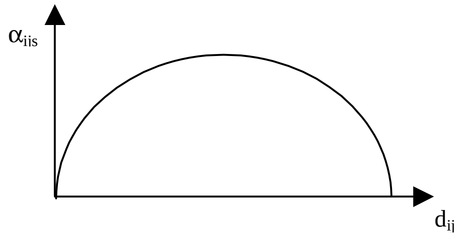
[21] Breschi et al (1999) employ this methodology to generate a *knowledge relatedness matrix,* based on all EPO patent applications over the period 1982-1993.

[22] Granstrand et al. (1997) point to the role of technological diversity in enhancing corporate growth and creating opportunities to engage in technology-related new businesses. Research investments in technological fields that are not directly related to the firm's core competencies are less likely to produce an innovative output in the short run, but become a crucial factor for dealing with systemic interdependencies and widening technological opportunities.

Figure 3



Accordingly, a non-linear specification, that combines the properties of "traditional" absorptive capacity (see Llerena and Oltra, 1999) and accounts for the above trade-off is proposed:

$$\alpha_{ijs} = c - 2\beta_{is}\left[\frac{1}{\sqrt{\underline{R}_{it}}} + \frac{1}{\sqrt{\underline{CR}_{it}}}\right] + g_i\left(a_s d_{ij} - b_s d_{ij}^2\right)$$

where c is a constant (the minimum value of α when the firm never performed formal R&D and $d_{ij}=0$). Table 2 summarises the definitions of the other variables and the proposed measurement criteria[23].

Table 2
Determinants of the relational research capacity

Variable/Parameter	Definition	Measurement
$\underline{R}_{it}$	Firm *i*'s research level at time *t*	$\underline{R}_i(t) = \Sigma_\tau (1-\delta)^\tau \; R(t-\tau)$
$\underline{CR}_{it}$	Firm *i*'s co-operative research level at time *t*	$\underline{CR}_i(t) = \Sigma_\tau (1-\delta)^\tau \; CR(t-\tau)$
β_{is}	Distance between firm *i*'s technological core and research field *s*	$\beta_{is} = 1 - S_{is}$ $S_{is} = \frac{C_i C_s}{\lVert C_i \rVert \lVert C_s \rVert} = \frac{\sum_{k=1}^{K} c_{ik} c_{sk}}{\sqrt{\sum_{k=1}^{K} c_{ik}^2 \sum_{k=1}^{K} c_{sk}^2}}$
g_i	Firm i's technological diversification level	$g_i = 1 - H_i$ $H_i = \Sigma_k s_k^2$
d_{ij}	Technological distance between firm *i* and partner(s) *j*	$d_{ij} = 1 - P_{ij}$ $P_{ij} = \frac{F_i F_j}{\lVert F_i \rVert \lVert F_j \rVert} = \frac{\sum_{k=1}^{K} f_{ik} f_{jk}}{\sqrt{\sum_{k=1}^{K} f_{ik}^2 \sum_{k=1}^{K} f_{jk}^2}}$
a_s, b_s	Technology-specific parameters	$a_s>0$ $b_s>0$: integrative case $a_s<0$ $b_s<0$: absorptive case

The properties of this specification and their consistency with the theoretical guidelines outlined above are analysed by means of partial derivatives[24].

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[23] See sections 4.1, 4.2 and 4.3 for details.
[24] In the following analysis subscripts are omitted for the sake of simplicity, unless they are required for clearer understanding.

The impact of cumulated R&D investment

Firm's in-house R&D increases relational research capacity, though at a decreasing

$$\frac{\partial \alpha}{\partial \underline{R}} = \beta \frac{1}{\underline{R}\sqrt{\underline{R}}} \geq 0$$

$$\frac{\partial^2 \alpha}{\partial \underline{R}^2} = -\frac{3}{2}\beta \frac{1}{\underline{R}^2\sqrt{\underline{R}}} \leq 0$$

rate;

$$\frac{\partial \alpha}{\partial \underline{CR}} = \beta \frac{1}{\underline{CR}\sqrt{\underline{CR}}} \geq 0$$

$$\frac{\partial^2 \alpha}{\partial \underline{CR}^2} = -\frac{3}{2}\beta \frac{1}{\underline{CR}^2\sqrt{\underline{CR}}} \leq 0$$

Firm's cumulated co-operative R&D increases the ability to "extract" valuable knowledge from co-operative projects, though at a decreasing rate.

The impact of technological relatedness

$$\frac{\partial \alpha}{\partial \beta} = -2\left[\frac{1}{\sqrt{\underline{R}_{it}}} + \frac{1}{\sqrt{\underline{CR}_{it}}}\right] \leq 0$$

$$\frac{\partial^2 \alpha}{\partial \underline{R} \partial \beta} = \frac{1}{\underline{R}\sqrt{R}} \geq 0$$

$$\frac{\partial^2 \alpha}{\partial \underline{CR} \partial \beta} = \frac{1}{\underline{CR}\sqrt{CR}} \geq 0$$

Given the level of internal and co-operative R&D, an increase in the distance between the firm's technological core and the research field (i.e. a decrease in the relatedness between firm's technological competencies and the research field) reduces α. However, the larger is β the greater is the marginal impact of R&D on relational research capacity[25].

The impact of cognitive distance: proximity/similarity trade-off

$$\frac{\partial \alpha}{\partial d_{ij}} = g(a_s - 2b_s d_{ij}) \qquad \frac{\partial^2 \alpha}{\partial d_{ij}^2} = -2gb_s$$

$\alpha_{max/min}$ when $d_{ij} = (a_s / 2b_s)$

[25] There is here a clear analogy with the β of Cohen and Levinthal model, that reflects the complexity of knowledge to be assimilated. The less tailored is the knowledge to firm's specific needs the greater is β. An increase in β makes R&D more critical to assimilating outside knowledge.

The impact of cognitive distance on α depends on the values of a_s and b_s, which reflect the features of the research field. As outlined in section 4.1, we can distinguish two interesting cases:

a) **Integrative environment**

$a_s > 0$ $\qquad$ $b_s > 0$

This is the case that gets closer to the intuitive idea of the proximity/similarity trade-off as represented in Figure 2: the "distance parabola" is concave (Figure A1 in Appendix A). When technology exhibits a high degree of systemic complexity and innovation demands the mastery of diversified competencies, cognitive proximity is not highly beneficial and may result in redundant knowledge, whereas pooling of complementary competencies gives rise to learning advantages, up to a distance threshold, beyond which communicability is negatively affected. Learning is fuelled by the combination of distinct, though interdependent competencies. However, when partners are much heterogeneous the effect of an increase in the distance becomes negative.

The greater a_s and the lower b_s, the higher is the maximum value of α, and the greater is the cognitive distance that corresponds to this value. At the limit, when a_s/b_s is very high, α monotonically increases over the range of technological distance ($0 < d_{ij} < 1$).

b) Absorptive environment

$a_s < 0$ $\qquad$ $b_s < 0$

The "distance parabola" is convex (Figure A2). The closer are partners in the cognitive space the higher is α. In other terms, heterogeneity reduces the knowledge produced by interacting. In this case, R&D levels determine the maximum value of α (the vertical intercept of the distance parabola).

This result is consistent with the characterisation of an "absorptive" environment. The technological field is characterised by relevant continuities in innovative activities and in the accumulation of technological capabilities. Interactions between agents that have cumulated knowledge in close research fields produce the best results.

The higher is the absolute value of a_s/b_s, i.e. the greater is the degree of cumulativeness and "specificity" and the more tacit is knowledge, the greater is the negative impact on α of a marginal increase in d_{ij}.

The impact of diversification

The degree of diversification of the firm's knowledge works as a scale factor on the relationship α_{ijs}/d_{ij}: g amplifies the marginal impact of d_{ij} on α_{ijs} when greater than 1, and reduces it when smaller than 1.

$$\alpha_d = g_i\,(a_s - 2b_s d_{ij})$$

$$\alpha_{dd} = -2g_i b_s$$

In other terms, the higher the degree of diversification the greater is the (positive or negative) effect of cognitive distance on relational research capacity, in terms both of level and marginal impact.

Within the first typology of technological environment (integrative case), the more diversified is the knowledge base, the more the firm can take advantage from the exchange of complementary knowledge with R&D partners. For any given value of d_{ij}, the greater is g the higher is α (Figure A3). This hypothesis is consistent with the findings of the empirical literature that investigates the technological diversification of large firms. According to Granstrand et al. (1997) and Patel and Pavitt (1997), driving forces of the investments beyond the firm's distinctive technological competencies are the need for exploring and assessing the new major opportunities emerging from the knowledge base and the need for managing and co-ordinating technical change with suppliers of components, equipment and materials. When the knowledge base exhibits a high level of systemic interdependence, the ability to master diversified technologies, or "technological languages", positively affects the relational research capacity.

On the opposite, when technology is specific and innovativeness benefits from cognitive similarity, sharing of common skills and problem-solving procedures, i.e. the technological environment exhibits the features of the absorptive typology outlined above, a high degree of diversification reduces firm's ability to assess, absorb and process knowledge flows stemming from R&D interaction (Figure A4).

When considering the marginal impact of a change in g (that implies a change in the distribution of patents over technological classes) on α, two effects need to be taken into account. In fact, a variation in g affects α *directly*, determining a translation of the "distance parabola" ($a_s d_{ij}$- $b_s d_{ij}^2$), and *indirectly*, by causing a change in d_{ij}. Given partner j's knowledge structure, a change in i's knowledge structure, as measured by the vector F_i, causes an increase or a decrease of d_{ij}.

The first effect is positive (negative) for positive (negative) values of a_s and b_s, while the sign of the indirect effect is a priori uncertain (see Appendix B for analytical details):

$$\frac{\partial \alpha}{\partial g_i} = \left(a_s d_{ij} - b_s d_{ij}^2\right) + \frac{\partial d_{ij}}{\partial g_i}\frac{\partial \alpha}{\partial d_{ij}}$$

Taking the integrative case as an example, the overall effect is positive when:

a) $(\partial\alpha/\partial d_{ij}) > 0$ $(\partial d_{ij}/\partial g_i) > 0$

we are on the ascending side of the "distance parabola" and an increase in diversification increases the distance with the partner;

b) $(\partial\alpha/\partial d_{ij}) < 0$ $(\partial d_{ij}/\partial g_i) < 0$

we are on the descending side of the "distance parabola" and a greater diversification reduces d_{ij}.

These results suggest that when the degree of tacitness is low, technology draws on a wide knowledge base and partners are relatively similar, an increase in diversification through investment in technological fields that do not closely relate to the partner's core makes the alliance more knowledge productive. On the other hand, when partners are very heterogeneous, a greater diversification in technological areas that are specific to the partner's knowledge structure benefits the alliance.

When the technological environment resembles the absorptive type, the effect of a change in g is positive if it reduces the differences with the partner's knowledge structure: a decrease in diversification (a greater specialisation) that reduces cognitive distance increases α.

Summing up, within a R&D alliance, internal R&D may be used by partners in order to change their diversification level and fine tune their knowledge structure to the technological characteristics of the partners.

The analysis so far does not explicitly take into account strategic factors. Firms may have strategic motivations when entering R&D alliances. Indeed, the choice of developing knowledge by means of co-operation, outsourcing, and/or in-house R&D is itself a greatly strategic decision. These motivations may greatly affect the output of the co-operative investment in terms of knowledge and innovation. However, as noted by several studies of alliance strategies (e.g. Hagedoorn, 1993; Narula and Hagedoorn, 1998), these motivations appear to be linked to the nature of the technological environment, to the conditions shaping the technological regime.

The typology of knowledge exchange within the RJV is highly related to the factors which influence the choice to enter a co-operative agreement. As a case in point, when appropriability of the output of co-operative R&D is low, there may be room for opportunistic behaviour. This may lower incentives for engaging in co-operation, or, once the agreement has been set, for engaging in effective exchange of tacit knowledge. On the other hand, when technological progress is systemic, i.e. it requires a cluster of related and complementary innovations, the firm can hardly innovate in isolation and looks for competencies that integrate its own ones.

Taking the technological area as a control variable should reduce the "strategic" bias that could affect the result of an empirical analysis directed to assess RJVs' effectiveness in terms of knowledge output and learning.

5 - A research agenda for empirical analysis

The formal analysis above presented works as a guideline for stating research hypothesis to be tested on empirical grounds.

Research Hypothesis

> *H1* – Cognitive distance between R&D partners plays a significant role for the effectiveness of R&D co-operation in terms of knowledge production and learning.
> *H1a* – The distance negatively affects knowledge production when the investigated technological field is characterised by knowledge cumulativeness, specificity and tacitness (absorptive case).

H1b – The distance positively affects knowledge production when the technological field draws on a diversified knowledge base, technological progress is systemic, knowledge is mostly codified or codifiable (integrative case).
H1c – The distance negatively affects knowledge production when partners are greatly heterogeneous.

H2 - Cumulated in-house R&D positively affects the ability to “extract” knowledge from R&D co-operation.

H3 – Co-operative experiences build a capability-to-interact and specific relational competencies that improve the relational research capacity.

H4a – The relatedness of the co-operative research field with the firm’s technological core positively affects the relational research capacity.
H4b – The less related are the research field and the firm’s technological core the more important is the level of cumulated in-house and co-operative R&D for technological learning.

H5a - Technological diversification positively affects relational research capacity when innovations are systemic.
H5b – Technological diversification negatively affects relational research capacity when technology is greatly specific and the degree of cumulativeness and tacitness is high.
H5c - A change in the level of technological diversification by means of in-house R&D can be used by partners to increase the effectiveness of the R&D alliance.

The research hypothesis above stated are the guidelines for future research concerning European RJVs. EU technology policy represents an extremely interesting domain for the application of the theoretical analysis, since co-operative R&D is given a central role by EU institutions.

The theoretical framework presented in this paper is meant to be tested employing data about RJVs that are supported or co-sponsored within the EUREKA Program (1,031 RJVs started between 1985 and 1996). and the EU 3rd and 4th Framework Programs (3,874 RJVs started between 1992 and 1996).

Following the mid-80s debate about European “technology gap”, the EUREKA Program was launched in 1985 in order to promote downstream collaborative projects and stronger links between firms and scientific institutions (Peterson, 1993). Co-operative R&D is central to the latest Framework Programs, that place much emphasis on the need for strengthening the connectivity of the European innovation system, while keeping a certain degree of variety (Soete and ter Weel, 1999).

The dataset comprises quantitative and qualitative information about both RJVs’ technological focus and RJVs’ members (source: CORDIS) including financial data and sector information (source: AMADEUS), and data about the patenting activity of the participating entities and of the holding groups to which those entities are related (source: EPO/CESPRI)[26] (see Appendix C for a description of the dataset).

The empirical analysis will focus on a few particular technological areas, which are on the top of EU political agenda and exhibit some of the characteristics of the two stylised environments identified above: the areas of Electronics, Information and Communication Technology (integrative case) and the area of Medicine and Biotechnology (absorptive case).

The evaluation of co-operative policies requires a thorough understanding of the "chemistry" of technological co-operation. The findings about significance and impact of relational research capacity may point at peculiar mechanisms of knowledge transmission and learning by interacting. The development and refinement of a relational research capacity may itself represent a policy aim. Accordingly, the test of this theoretical framework is the first step towards a more general evaluation of the strategies employed to increase the connectivity of the EU innovation system on the one hand and to promote technological variety on the other.

[26] The construction of the EU-RJV dataset is part of the Targeted Socio-Economic Research Project of the European Commission (DG XII) "Know for Innovation", which aims at examining the extent, magnitude, and type of innovation-related knowledge flows affecting the European industry and at evaluating the effectiveness of knowledge transmission mechanisms in raising the ability of European industry to innovate and create economic value.

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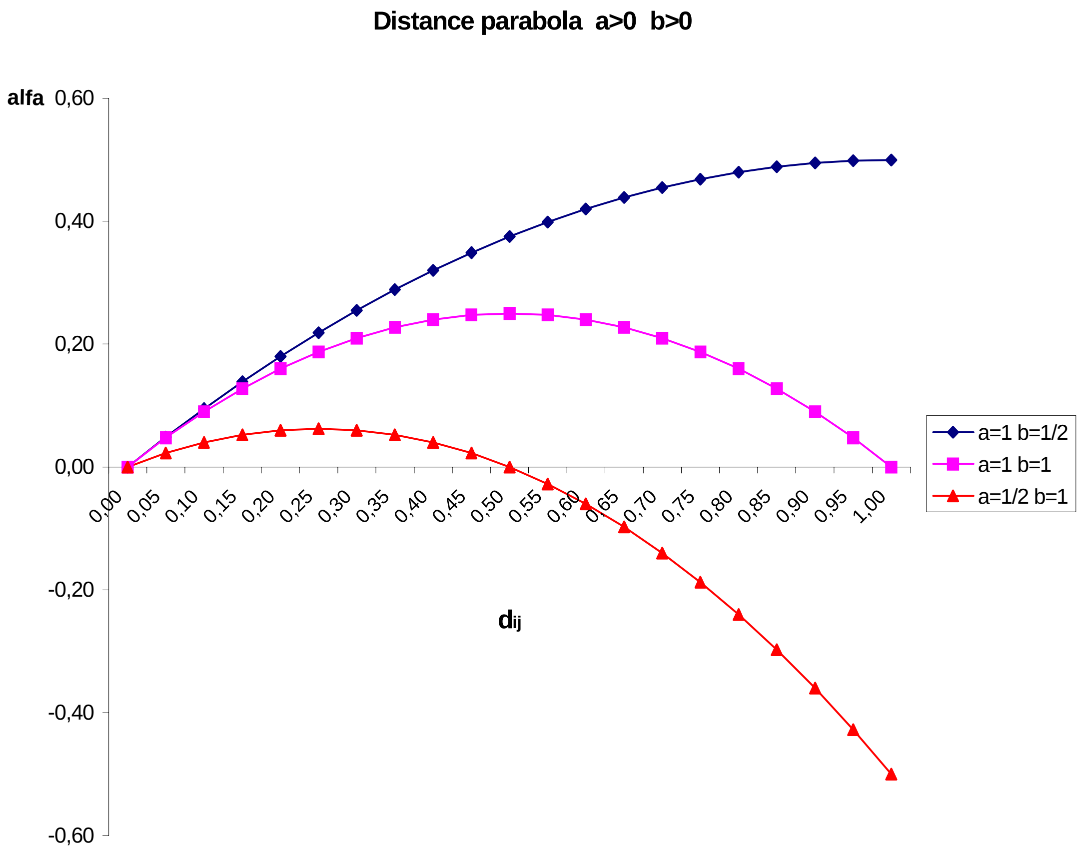
APPENDIX A

Figure A1

Integrative environment

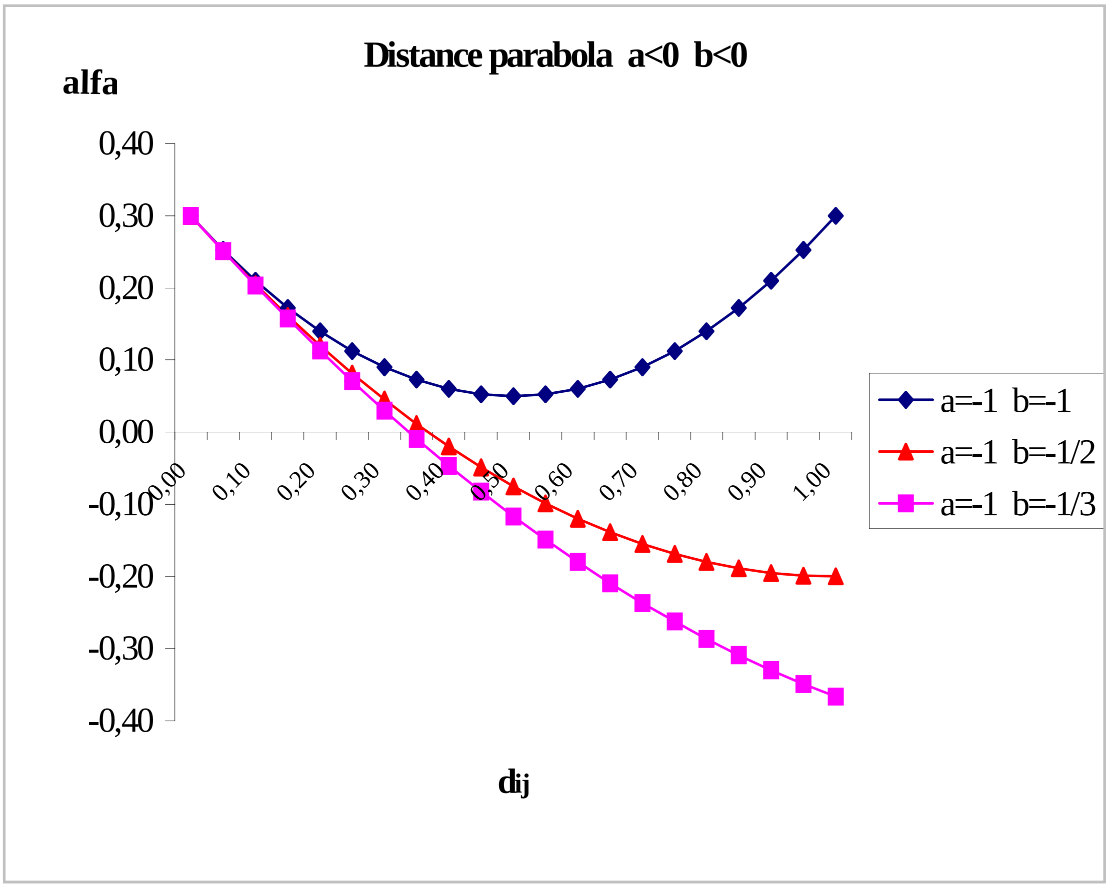
* The constant term and R&D levels are assumed to be zero. However, an increase in those levels



simply shifts the vertical intercept upwards

Figure A2

Absorptive environment*



*The intercept (the exogenous relational research capacity) is set equal to 0.3

Figure A3

Integrative environment: diversification effect

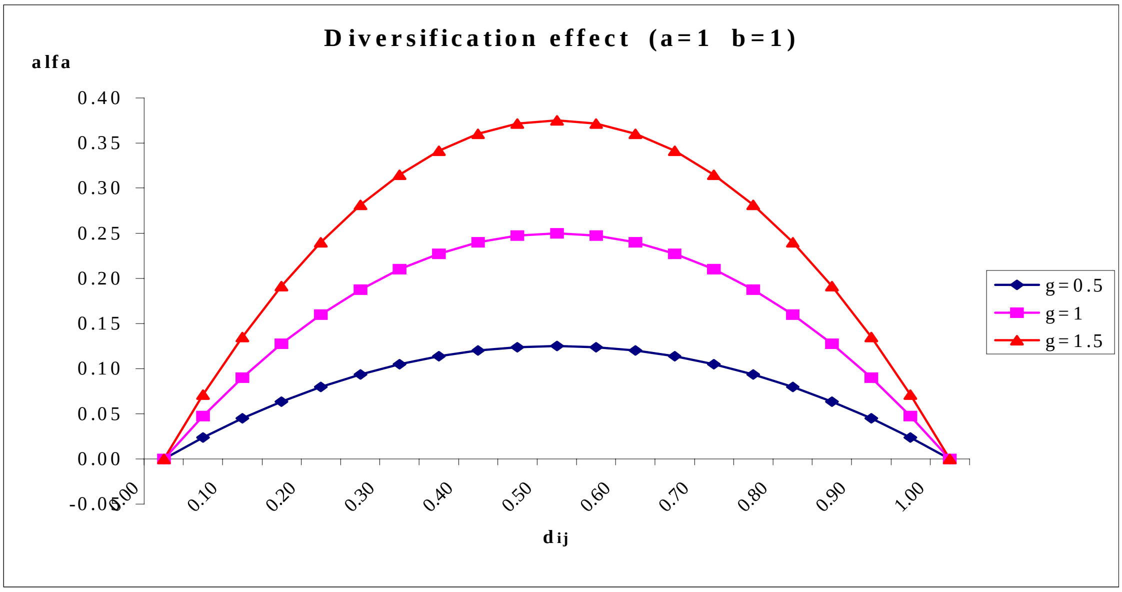
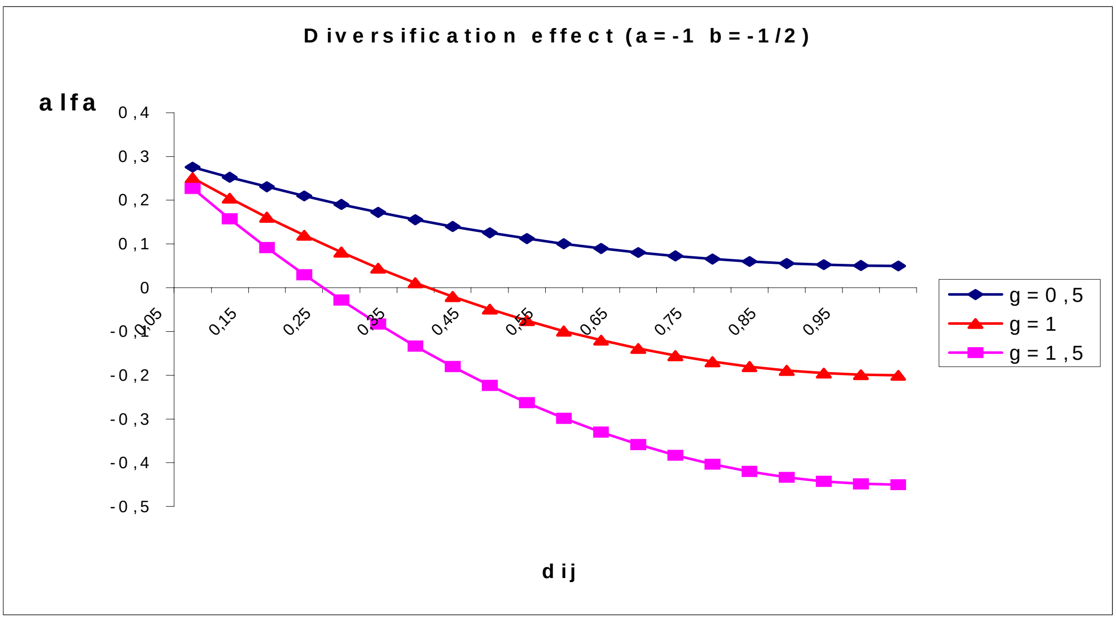


Figure A4

Absorptive environment: diversification effect



APPENDIX B

The impact on relational research capacity of a change in diversification

$$\alpha_i = c - 2\beta_i\left[\frac{1}{\sqrt{\underline{R}_{it}}} + \frac{1}{\sqrt{\underline{CR}_{it}}}\right] + g_i\left(a_s d_{ij} - b_s d_{ij}^2\right)$$

$$\frac{\partial\alpha}{\partial g} = \left(a_s d_{ij} - b_s d_{ij}^2\right) + g\left(a_s \frac{\partial d_{ij}}{\partial g} - 2b_s d_{ij}\frac{\partial d_{ij}}{\partial g}\right) =$$

$$= \left(a_s d_{ij} - b_s d_{ij}^2\right) + g\frac{\partial d_{ij}}{\partial g}\left(a_s - 2b_s d_{ij}\right) =$$

$$= \left(a_s d_{ij} - b_s d_{ij}^2\right) + g\frac{\partial d_{ij}}{\partial g}\frac{\partial\alpha}{\partial d_{ij}}\frac{1}{g} =$$

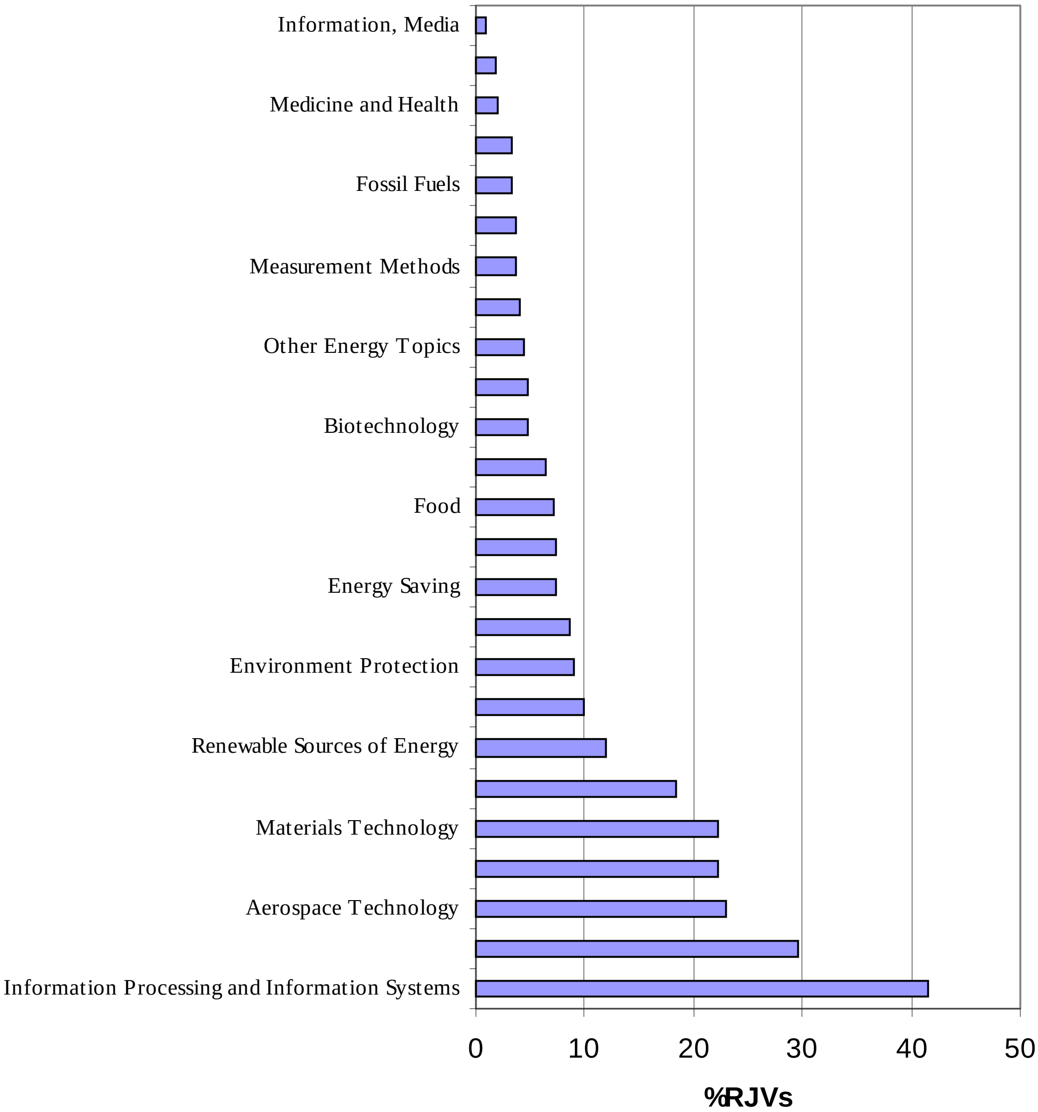
$$= \left(a_s d_{ij} - b_s d_{ij}^2\right) + \frac{\partial d_{ij}}{\partial g}\frac{\partial\alpha}{\partial d_{ij}}$$

APPENDIX C

EU – RJVs DATASET

Figure C1
3rd – 4th Framework Programs' RJVs by technological area

3, 874 RJVs (at least one participant from the private sector), 1992-1996

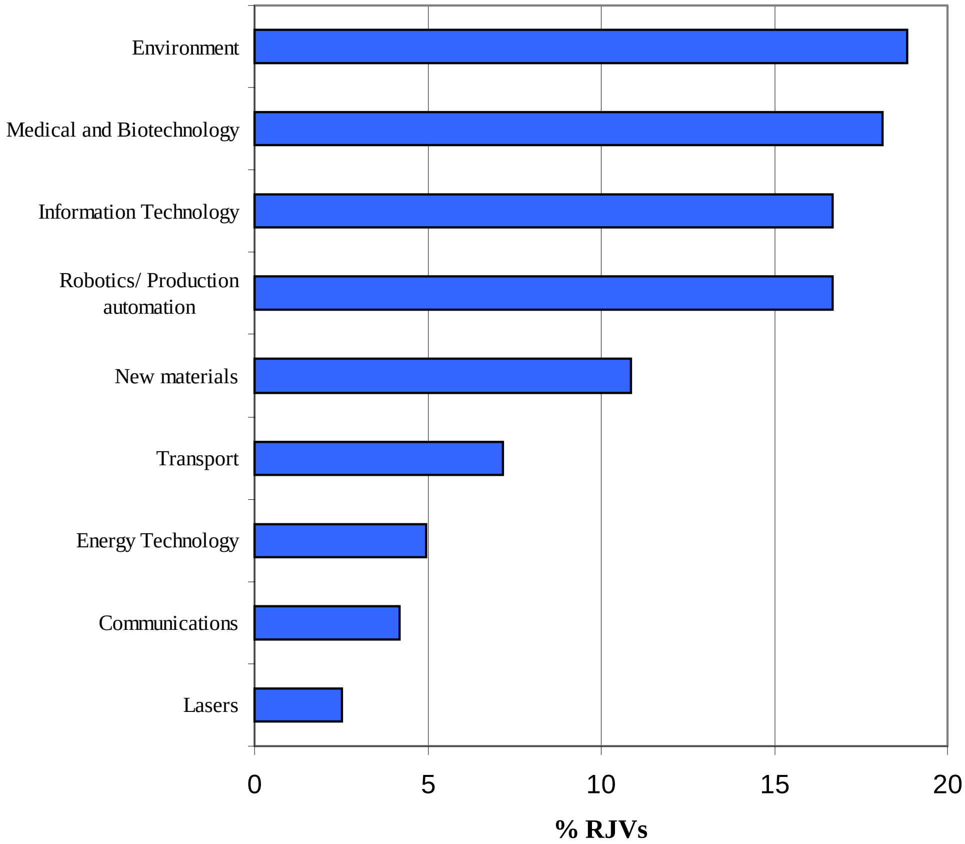


* Technological areas do not sum to 100. Most RJVs refer to two or three technical areas, thus are counted more than once

Figure C2

EUREKA Program's RJVs by technological area

1,031 RJVs, 1985- 1996



*Technological areas sum to 100, since each RJV refers to a single technical area

Figure C3
3rd – 4th Framework Programs' RJVs by participants' country

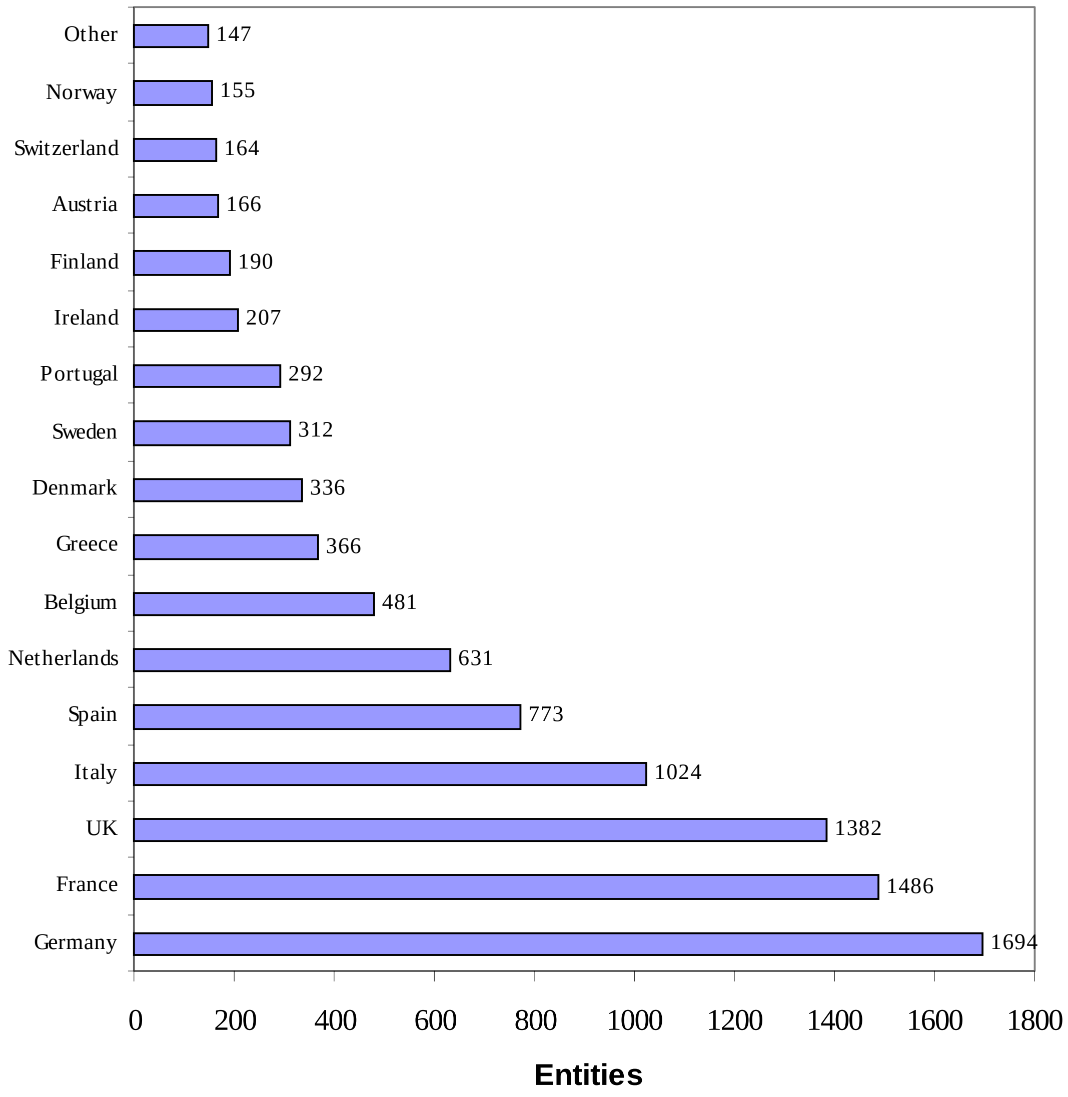
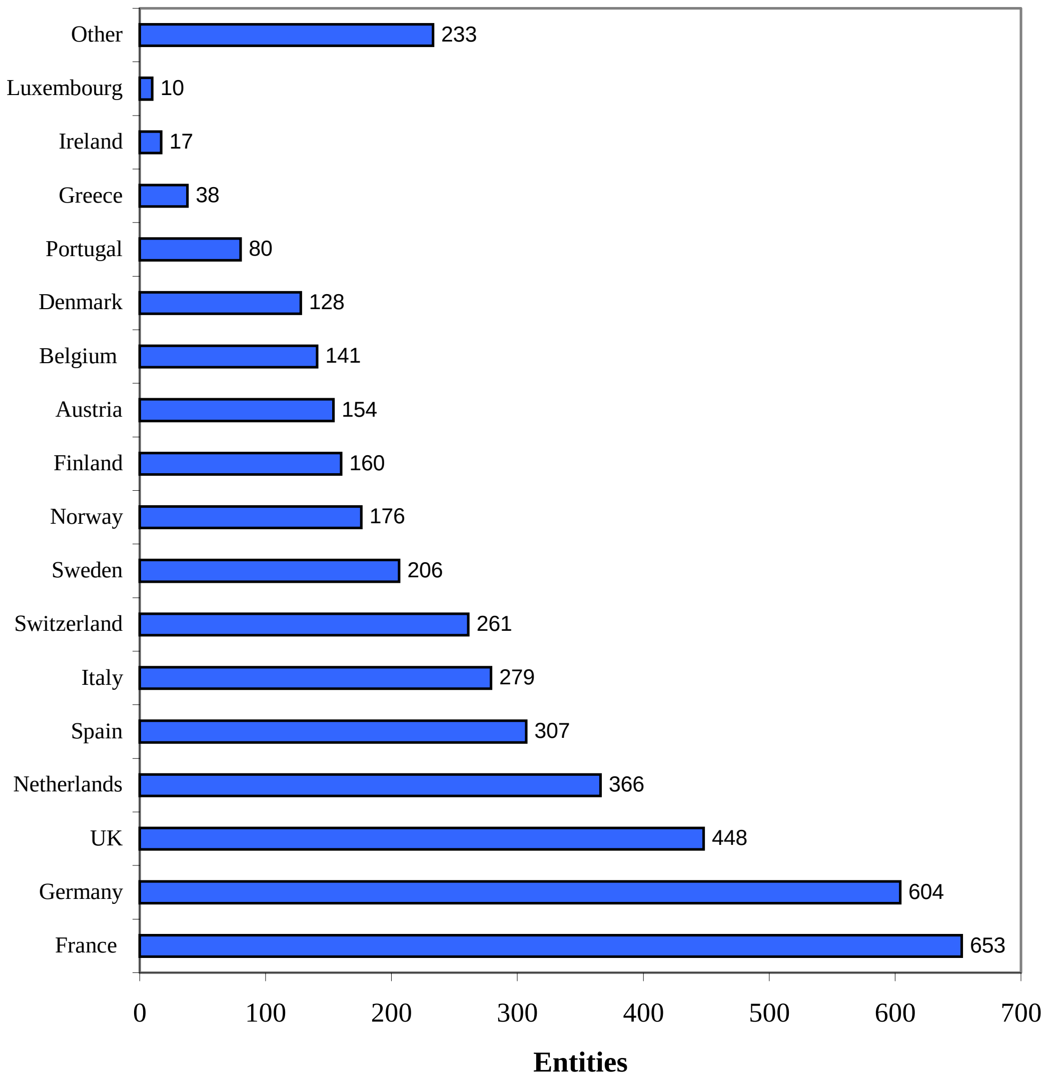


Figure C4

EUREKA Program's RJVs by participants' country



FRAMEWORK PROGRAMS

Table C1
Information Technology – Electronics Area

Program Acronym	***BUDGET*** (million ECU)	RJVs	***ENTITIES***[a]
ACTS	671	151	1426
ESPRIT 3	1532	483	3871
ESPRIT 4	2057	398	2171
TELEMATICS 2C	898	282	1834
IT AREA	***5158***	***1314***	***4009***[b]

[a]Entity refers to business units, University laboratories, R&D centres, public administrations, non commercial organisations.
[b]The total number of entities in the technological area does not result from the sum of the entities in each program. Most entities have participated to more than one program, the total for the area is corrected in order not to include double counting.

Table C2
Medical and Biotechnology Area

Program Acronym	BUDGET (million ECU)	RJVs	***ENTITIES***[a]
BIOMED 1	151	3	11
BIOMED 2	358	40	283
BIOTECH 1	186	33	401
BIOTECH 2	588	108	890
M&B AREA	***1283***	***184***	***576***[b]

[a]Entity refers to business units, University laboratories, R&D centres, public administrations, non commercial organisations.
[b]The total number of entities in the technological area does not result from the sum of the entities in each program. Most entities have participated to more than one program, the total for the area is corrected in order not to include double counting.

FRAMEWORK PROGRAMS

Legend C

RJVs types of collaboration in terms of participants organisational characteristics

A	Firm – University – Research Centre	E	Firm – University – Research Centre - Other
B	Firm – University	G	Firm – Research Centre - Other
C	Firm – Firm	H	Firm – Other
D	Firm – Research Centre	I	Firm – University- Other

Figure C5

3rd- 4th FWPs (3780 RJVs)

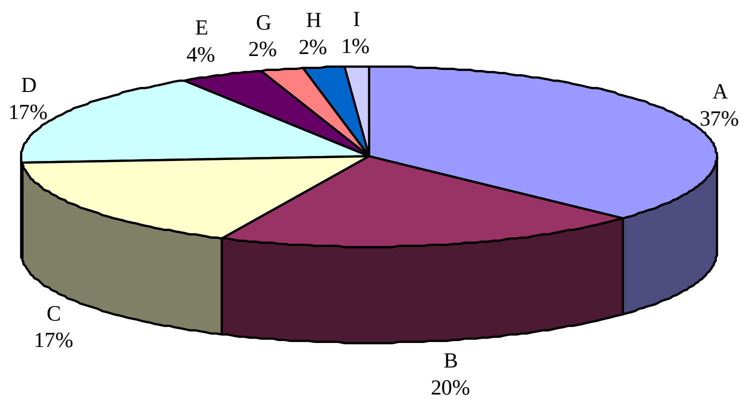


Figure C6

IT Area (1314 RJVs)

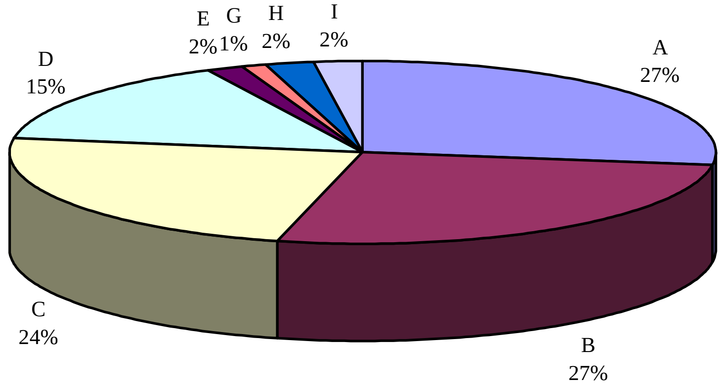
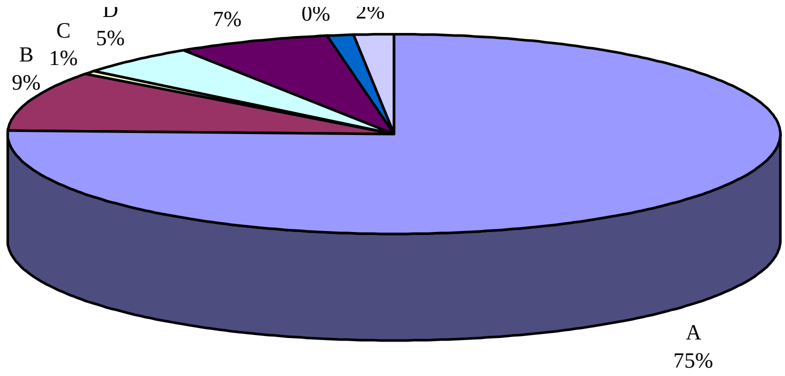


Figure C7

M&B Area (184 RJVs)



EUREKA PROGRAM

Table C3

Information and Communication Technology Area

Technological Area	BUDGET (million ECU)	RJVs	***ENTITIES***[a]
Information Technology	8077.84	172	984
Communication	1935.7	43	254
ICT AREA	***10013.54***	***215***	***1178***[b]

[a]Entity refers to business units, University laboratories, R&D centres, public administrations, non commercial organisations.

[b]The total number of entities in the technological area does not result from the sum of the entities in each program. Most entities have participated to more than one program, the total for the area is corrected in order not to include double counting.

Table C4

Medical and Biotechnology Area

Technological Area	BUDGET (million ECU)	RJVs	***ENTITIES***[a]
M&B AREA	***908.83***	***187***	***676***[b]

[a]Entity refers to business units, University laboratories, R&D centres, public administrations, non commercial organisations.

[b]The total number of entities in the technological area does not result from the sum of the entities in each program. Most entities have participated to more than one program, the total for the area is corrected in order not to include double counting.

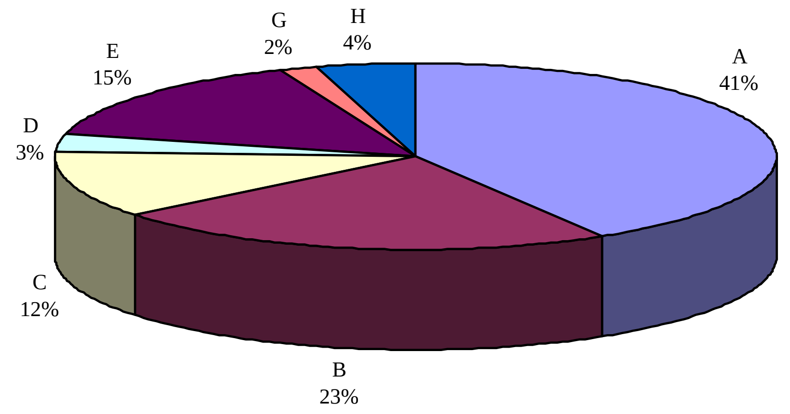
EUREKA PROGRAM

RJVs types of collaboration in terms of participants organisational characteristics

(see Legend C)

<u>Figure C8</u>

<u>Total EUREKA (1030 RJVs)*</u>



*1 RJV is not classified

<u>Figure C9</u>

<u>ICT Area (215 RJVs)</u>

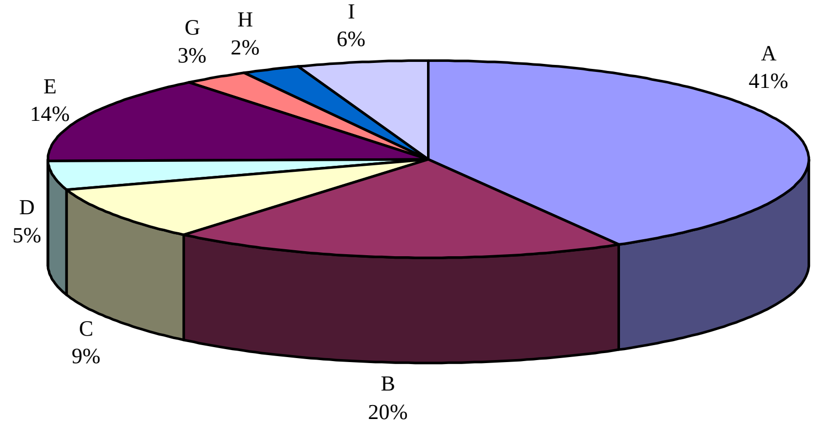
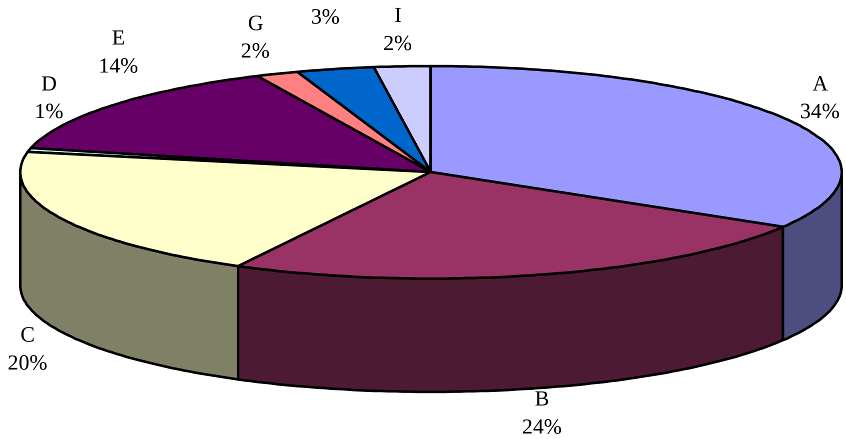


Figure C10

M&B Area (187 RJVs)



Danish **R**esearch **U**nit for **I**ndustrial **D**ynamics

The Research Programme

The DRUID-research programme is organised in 3 different research themes:

- ***The firm as a learning organisation***
- ***Competence building and inter-firm dynamics***
- ***The learning economy and the competitiveness of systems of innovation***

In each of the three areas there is one strategic theoretical and one central empirical and policy oriented orientation.

Theme A: The firm as a learning organisation

The theoretical perspective confronts and combines the resource-based view (Penrose, 1959) with recent approaches where the focus is on learning and the dynamic capabilities of the firm (Dosi, Teece and Winter, 1992). The aim of this theoretical work is to develop an analytical understanding of the firm as a learning organisation.

The empirical and policy issues relate to the nexus technology, productivity, organisational change and human resources. More insight in the dynamic interplay between these factors at the level of the firm is crucial to understand international differences in performance at the macro level in terms of economic growth and employment.

Theme B: Competence building and inter-firm dynamics

The theoretical perspective relates to the dynamics of the inter-firm division of labour and the formation of network relationships between firms. An attempt will be made to develop evolutionary models with Schumpeterian innovations as the motor driving a Marshallian evolution of the division of labour.

The empirical and policy issues relate the formation of knowledge-intensive regional and sectoral networks of firms to competitiveness and structural change. Data on the structure of production will be combined with indicators of knowledge and learning. IO-matrixes which include flows of knowledge and new technologies will be developed and supplemented by data from case-studies and questionnaires.

Theme C: The learning economy and the competitiveness of systems of innovation.

The third theme aims at a stronger conceptual and theoretical base for new concepts such as 'systems of innovation' and 'the learning economy' and to link these concepts to the ecological dimension. The focus is on the interaction between institutional and technical change in a specified geographical space. An attempt will be made to synthesise theories of economic development emphasising the role of science based-sectors with those emphasising learning-by-producing and the growing knowledge-intensity of all economic activities.

The main empirical and policy issues are related to changes in the local dimensions of innovation and learning. What remains of the relative autonomy of national systems of innovation? Is there a tendency towards convergence or divergence in the specialisation in trade, production, innovation and in the knowledge base itself when we compare regions and nations?

The Ph.D.-programme

There are at present more than 10 Ph.D.-students working in close connection to the DRUID research programme. DRUID organises regularly specific Ph.D-activities such as workshops, seminars and courses, often in a co-operation with other Danish or international institutes. Also important is the role of DRUID as an environment which stimulates the Ph.D.-students to become creative and effective. This involves several elements:

- access to the international network in the form of visiting fellows and visits at the sister institutions
- participation in research projects
- access to supervision of theses
- access to databases

Each year DRUID welcomes a limited number of foreign Ph.D.-students who wants to work on subjects and project close to the core of the DRUID-research programme.

External projects

DRUID-members are involved in projects with external support. One major project which covers several of the elements of the research programme is DISKO; a comparative analysis of the Danish Innovation System; and there are several projects involving international co-operation within EU's 4th Framework Programme. DRUID is open to host other projects as far as they fall within its research profile. Special attention is given to the communication of research results from such projects to a wide set of social actors and policy makers.

DRUID Working Papers

96-1 **Lundvall, Bengt-Åke:** The Social Dimension of the Learning Economy. (ISBN 87-7873-000-7)

96-2 **Foss, Nicolai J.:** Firms, Incomplete Contracts and Organizational Learning. (ISBN 87-7873-001-5)

96-3 **Dalum, Bent and Villumsen, Gert**: Are OECD Export Specialisation Patterns Sticky?' Relations to the Convergence-Divergence Debate. (ISBN 87-7873-002-3)

96-4 **Foss, Nicolai J:** Austrian and Post-Marshallian Economics: The Bridging Work of George Richardson. (ISBN 87-7873-003-1)

96-5 **Andersen, Esben S., Jensen, Anne K., Madsen, Lars and Jørgensen, Martin:** The Nelson and Winter Models Revisited: Prototypes for Computer-Based Reconstruction of Schumpeterian Competition. (ISBN 87-7873-005-8)

96-6 **Maskell, Peter:** Learning in the village economy of Denmark. The role of institutions and policy in sustaining competitiveness. (ISBN 87-7873-006-6)

96-7 **Foss, Nicolai J. & Christensen, Jens Frøslev:** A Process Approach to Corporate Coherence. (ISBN 87-7873-007-4)

96-8 **Foss, Nicolai J.:** Capabilities and the Theory of the Firm. (ISBN 87-7873-008-2)

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