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Firm performance, innovation and networking activities
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Abstract

The paper addresses the relevancy of networking activities and R&D as main drivers of productivity performance and ouput innovation, for small and medium enterprises (SME) playing in a local economic system. Given the intangible nature of many techno-organisational innovation and networking strategies, original recent survey data for manufacturing and services are exploited.

The aim is to provide new evidence on the complementarity relationships concerning different networking activities and R&D in a local SME oriented system in Northern Italy. We first introduce a methodological framework to empirically test complementarity among R&D and networking, in a discrete setting. Secondly, we consequently present empirical evidence on productivity drivers and on complementarity between R&D and networking strategies, with respect to firm productivity and process/product output innovation.

R&D arises a main driver of innovation and productivity, even without networking. The complementarity between diversified networking activities and R&D/innovation is found only in a discrete setting, signalling the necessity of surpassing critical thresholds. In any case, the complementarity with networking is a consequential step, following investments in R&D. Networking by itself cannot thus play a role in stimulating productivity and innovation. It can be a complementary factor in situations where cooperation and networking are needed to achieve economies of scale and/or to merge and integrate diverse skills, technologies and competencies. This is compatible with a framework where networking is the public part of an impure public good wherein R&D plays the part of the private-led driving force towards structural break from the business as usual scenario.

Managers and policy makers should be aware that in order to exploit asset complementarity, possibly transformed into competitive advantages, both R&D and networking are to be sustained and favoured. our evidence suggests that R&D may be a single main driver of performance. Since R&D expenditures are associated with firm size, a policy sustain is to be directed towards firm enlargement. After a certain threshold firms have the force to increase expenditures. The size effect is nevertheless non monotonous. Then, but not least important, for the majority of firms still remaining under a critical size threshold, policy incentives should be directed to R&D in connection with networking, through which a virtuous circle may arise. It is worth noting that it is not networking as such the main engine. Networking elements are crucially linked to innovation dynamics; it is nevertheless innovation that explains and drives networking, and not the often claimed mere existence of local spillovers or of a civic associative culture in the territory. Such public good factors exist but are likely to evolve with and be sustained by firm innovative dynamics.

JEL: D21, L25, O3, O14, Z13

Keywords: firm competitiveness, innovation, R&D, networking, complementarity, local economic system

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0. Introduction

The recent interest of economic literature on the links among firms' networking innovation and R&D investments is part of a more general attitude of economic analysis, considering a larger spectrum of productive inputs, including both intangible forms of capital (such as organization, human resources, non technological innovation) and forms of capital external to the firm (as social capital, innovation networking). These extensions aim to improve the analysis on the relationships among firms' innovative strategies, investments in different capital forms, and performances.

The attention devoted to networking reflects different real-world situations where inter-firm cooperation is the primary and leading key to successful performance of both the single firms and the whole network. Without entering into the specific debate over taxonomy, we refer to this as either a "cluster" or a "district" of firms. What matters is that at some point firms need to join their efforts for achieving benefits which derive from and build on public-like forms of investments. This necessary joint effort to establish voluntary cooperative schemes, by which achieving goals specific to the network but appropriable by participants, characterises most forms of (i) voluntary agreements, (ii) inter-firms intra district cooperation, (iii) inter-firms inter-districts cooperation. The relevance of points (i)-(iii) as engines for innovation and growth at a regional level has increased over the last decades, following both the less prominent role of the state as "regulator" (top down approach), and the reshaping of governance and business strategies within the post-fordist society. Actually socio-economic changes occurring in the post fordist (post-industrial) era shift the focus of interest from man-made forms of capital to human, environmental and social capital assets. Further, market and non-market "horizontal" networks play a major role with respect to "vertical" and hierarchical relationships, bringing about a new scenario described by a cultural change in local and national production. Finally, "intentional" (multilateral) externalities turn over standard Marshallian "unintentional" externalities in explaining growth and innovation processes. The community benefits from positive network externalities; nevertheless, differently from exogenous spillovers, the voluntary and intentional production of joint social benefits is costly; therefore incentives matter.

Some recent works dealing with high performance practices, innovation, networking and spillovers occurring in local district systems, have paid great attention to the notion of complementarity. The question is whether the relationships of complementarity among different drivers of firms' productivity may themselves be considered as partially intangible factors of competitive advantages for firms, adding to, or substituting, the role of the other more usual productivity drivers. Anyway, it sometimes happens that some of the links existing among different productive factors do not necessarily turn out to be complementary relations.

The aim of the paper is to focus on the complementarity links between firms' internal R&D activities and networking activities. What we want to investigate is whether this relationship of complementarity may itself be considered a firm's productivity driver, and whether this relationship passes the test of complementarity both on theoretical and on empirical grounds, or in which specific circumstances this happens. To pursue the proposed aim, we first introduce a methodological framework useful to empirically test complementarity among R&D and networking, in a discrete setting. Secondly, we consequently present empirical evidence on complementarity between the two variables, with respect to firm productivity, exploiting detailed and specific survey-based data.

The paper is organized as follows. Section one introduces the analysis of networking activities and innovation dynamics, jointly with the issue of complementarity among productive factors. The recent research streams are briefly commented on. In section two, a methodological framework is presented, wherein the complementarity between R&D and networking is analysed through the supermodularity of firms' productivity function; the database and the context are then presented. Section three comments on and presents the empirical framework and discusses some methodological issues, introducing the core empirical part, subdivided first in an analysis of productivity drivers and then of specific investigations of complementarity relationships. The last section concludes the paper by summarising results and offering insights for further research.

1. Innovation, networking and complementarity

From the previous introduction the role of "intentional cooperative strategies" as a form of demand for "new institutions", framed around new rules emerges as clearly relevant, endogenously created and bottom-up driven. Those bottom up coalitions share the risks of investing in community specific knowledge (vs. firm specific assets). Moreover, coalitions should usually rely on informal rules and non coercive incentives for sustaining *effective and efficient* agreements.

Reasoning on firms networking helps to clarify a central issue for any theoretical and applied analysis on the determinants of innovation. A key point concerns the role of firm dimension (firm size) in achieving innovation intended as a breakout from established paradigms. The applied microeconomic literature which focuses on networks, social capital and spillovers in industrial districts deals with the issue by including both firm size and "social capital-network relationship" proxies as explanatory factors of innovation, in order to test which potential driving force is relevant (or more relevant). That is, in the words of Nooteboom (1999), who places his emphasis on different hypotheses developed by Schumpeter and on ambiguous results obtained by the recent empirical research: "the relevant variable is not firm size, but degree of integration and the strength of links" (Nooteboom, 1999, p.143). Depending on network linkages and on the organisational structure of the firm, both small and large organisations may be engines for innovation as "creative destruction". The author correctly stresses the point, further highlighting the two primary elements which define the nature and intensity of network linkages: cognitive proximity and trust.

Within this framework of analysis, another recent, crucial point of investigation revolves around the notion of complementarity.

In defining networking as an external source of innovation and productivity enhancement, it follows that network relations and high-performance oriented organizational strategies are indeed possibly linked by complementarity relationships, since they may represent external and internal ways of innovating the organizational firm structure.

The complementarity hypothesis recently received increasing attention stemming from the literature dealing with innovation, high performance practise, networking and spillovers occurring in local district systems. Complementarity has been addressed both from a theoretical and an empirical perspective over the past ten years, taking both main stream and heterodox approaches into account[1].

The relevancy of complementarity among drivers of performances has been underlined by various works, dealing with the relationship between innovation strategies and performances at firm level. Since the mid nineties, those contributions have highlighted the limited short-run effects of strategies biased towards organisational (cost) efficiency and the higher potential for increasing long-run performances of innovation-based management of firms (Huselid, 1995; Black, Lynch, 1996, 2001, 2004; Ichniowski, Shaw, Prennushi, 1997; Michie, Sheehan, 2003, 2005; Bryson, Forth, Kirby, 2005; Matteucci, O'Mahony, Robinson, Zwick, 2005; Cassidy, Gorg, Strobl, 2005). The questions relevant to this approach and to the more circumscribed environment of complementarity are "by what mechanisms a high performance work system affects firm performance" and "how can these systems represent *a source of sustained value creation, rather than simply locus of cost control*?" (Becker, Huselid, 1998).

We do not aim at surveying the mostly applied oriented literature on complementarities. Summing up, in recent works complementarity is analysed concerning diverse factors affecting firm performance such as technological innovation, R&D, organisational innovations, high performance practices, training. Networking is analysed both as a holistic factor and by differentiating cooperation with respect to other firms, universities, and suppliers. Various hypotheses of complementarity are explored, both with respect to their effects on firm performance (productivity, profits) and regarding innovation performances. We refer to Laursen, Foss (2003) and Laursen, Mahnke (2001) who focus on techno-organisational factors, organisational bundles and firm innovation performances. Cristini, Gaj, Leoni (2004) pursue a similar complementarity assessment but within a more mainstream production function approach. Lokshin, Carree, Belderbos (2004) and Galia, Legros (2004a,b) who exploit CIS data for analysing obstacles to innovation (in the spirit of Mohnen, Roller, 2005) and complementarities between different networking dynamics, providing evidence for the European environment. Bresnahan, Brynjolfsson, Hitt (2002), Brynjolfsson, Hitt, Yang (2002), Brynjolfsson, Hitt (1997, 2000, 2003) extensively analyse ICT and techno-organisational complementarities with respect to firm performance on the US environment. More recently, Aral, Weill (2005) focus on ICT innovations; Guidetti, Mancinelli, Mazzanti (2006) analyse formal and informal training links; Cassiman, Veugelers (2005), Belderbos et al (2004), Veugelers, Cassiman (2005) provide other evidence on the EU arena, focusing on large manufacturing firms, with a focus on heterogeneity in R&D cooperation strategies by firm typology and sector, networking between firms and universities, internal R&D and external knowledge acquisition (following the R&D and spillovers focused analysis by Cassiman, Veugelers, 2002). Those are to our knowledge the main recent contributions dealing with complementarity among productive inputs or, more generally, among firm modules.

Taking as boundaries the investigation on complementarities between tangible and intangible productive inputs, we argue that this literature, though it has shown a promising and increasingly robust and relevant

[1] A critical survey of the literature is not the aim of the paper; Tab.1 sums up main recent empirical contributions on complementarity. See also Pini (2006).

outcomes, is still developing. As it was for the now more mature literature on innovation and firm performance, there is room for providing incremental added value.

As far as empirical analysis is concerned, complementarity is analysed both by a mainstream approach exploiting production function framing, and by less orthodox models like innovation functions or empirical models using productivity or other firm performances as dependent variables. It is worth noting that all those approaches, more or less mainstream, try to verify causal links between input and ouput variables. Complementarity is also studied, along a different conceptual and empirical perspective, by more evolutionary, systemic-oriented and dynamic-focused streams of research. For example, complementarity in Teece (1996) emerges as associated with the joint asset specificity of some inputs and innovations, which may produce idiosyncratic not replicable organisational frameworks, leading to higher performance and rents. In other words, crucial complementarity links, such as the one regarding R&D and networking examined in this paper, may act as partially intangible factors of competitive advantages for firms, adding to or substituting the role of more usual drivers like size, R&D internal expenditures, etc..

An idea of co-specialisation between productive factors emerges (Teece, 1986). This asset specificity or co-specialisation between firms' tangible and intangible assets is a way of capturing and defending the rents of techno-organisational innovations, within a perspective which goes beyond the standard boundaries of the firm, and is potentially alternative to patenting activities (Gu, Tang, 2004).

Teece (1996) theoretically examines the extent to which innovative capacity is dependent on the formal and informal structures of the firm, as well as the network of external linkage that they possess. The complementarity between productive assets or firm modules in a broader sense emerges itself as an intangible asset. This asset is specific, non-transferable and non-modular (Langlois, 2002). We find a specific link to the main features of technological innovation, for example, in a nutshell: (i) technological interrelatedness (innovation is characterised by technological interrelatedness between various subsystems. Linkages to other technologies, to *complementary assets* and to users must be maintained if innovation is to be successful); (ii) inappropriability (accordingly, investment in innovative activity may not necessarily yield property which can be reserved for the exclusive use of the innovator). As far as networking as external intangible asset is concerned, its role for the innovative capacity (development and adoption of innovations) and its complementarity with other assets/performance drivers of the firm (i.e. R&D) are of fundamental importance.

Though the increasing empirical evidence on complementarity takes different directions, studies which focus on networking and innovation are quite rare, given, among other reasons, the paucity of reliable micro-data. Networking is, in fact, a typical non-market activity rarely elicited in official statistics, as well as other intangible assets. Cainelli, Mancinelli, Mazzanti (2007) and Mancinelli, Mazzanti (2004) theoretically and empirically analyse the link between R&D and networking/ social capital. Within a theoretical framework that considers social capital as the public component of the impure public good[2] R&D, they

[2] In the micro-economic literature (Cornes, Sandler, 1984; 1986), an impure public good, or mixed-public good, is a good which jointly gives private and public benefits. A typical example is that of an individual who, by being inoculated against an infectious disease, confers both a private benefit on himself and a public benefit by reducing the risk of spreading the disease through the community. In this case inoculation is the impure public good.

show that the 'civic culture' of the district area in which a firm works is not a sufficient incentive to increase its investment in SC. Social capital/networking dynamics might positively and complementarily evolve only if the opportunity cost of investing in innovation is sufficiently low. When empirical evidence confirms that this complementarity plays a key role, the policy effort should be targeted toward both market and non-market characteristics, rather than solely to the production of local public goods or innovation inputs as independent elements of firm performances. The difference is important as far as policy effectiveness is concerned. Other recent relevant works are Fritsch, Franke (2004) and Belderbos, Carree, Lokshin (2004). The first work estimates a knowledge production function in order to verify the impact of R&D investments, cooperative R&D and knowledge spillovers on the adoption of patents and the number of registered patents. The second analyses the effect of various cooperative activities (with subcontractor, with other competitors, university, etc..) on innovation and productivity, finding weak evidence for the networking-productivity link and heterogeneous evidence, depending on the cooperative activity, for the link between networking R&D and ouput innovation. Mol (2005) instead focuses on innovation and outsourcing. He questions the 'conventional' wisdom which associates innovation with the advantages of vertical integration, and proposes as an alternative an innovation driving role of networking and outsourcing specifically. This is a 'relational view', (Mol, 2005, p. 575), which considers establishing connections with outside suppliers and is crucial in terms of networking and learning-by-interacting. He tests this hypothesis by empirically analysing the link between R&D and outsourcing activities, finding that, though R&D was likely to be a traditional impediment to outsourcing in manufacturing industries in the past, current evidence may suggest that firms in R&D intensive industries have increasingly started to rely on relations with outside suppliers. This is an ancillary element in our reasoning, to the extent that outsourcing is an organisational innovation and lies within the networking arena of firms[3].

Following the reasoning described above, our aim is to focus on the complementary relation between firms' internal R&D activities and networking activities.

Our paper is aimed at adding further empirical evidence on the following aspects. First, the literature has particularly focused on large firms belonging to manufacturing sectors. Our analysis, instead, exploits data for a local economic system composed of manufacturing and market service firms, where small medium enterprises[4] (SME) are dominant, and synergies between R&D and networking are a crucial way for achieving (new) competitiveness, as a primary alternative to more usual economies of scale. With this respect it exists a role for public policies at regional level. Secondly, we primarily test complementarities taking as main elements R&D and networking, according to a theoretical framework which will be discussed below. Then, though the core analysis is between internal R&D and networking, defined by various agents' relationships with firms and institutions, we extend the empirical assessment to a larger frame where other techno-organisational innovations (including outsourcing and ICT) are considered. With respect to the

[3] Though our definition of networking in the present paper is more coherent with informal and voluntary agreements between firms that mainly exchange intangible assets like knowledge and innovation, or produce knowledge and innovation by cooperating. Outsourcing can be characterised by and correlated with such networking features, most likely in R&D intense environments. If this happens, outsourcing stays properly within the boundaries of our analysis.

[4] SME based economic systems present the following features: (i) a high density of firms whose size is no more than medium; (ii) a considerable number of district firms, characterized by few but strong production specializations (Brusco, 1982).

objective function, we test complementarity relationships primarily on productivity, but also on ouput innovation adoptions by firms. R&D and networking are main drivers of performance for SME dense areas. It is highly relevant to inform the management and the policy maker the extent to which complementarities is likely to play a virtuous role.

Following the definition of complementarity given in Topkis (1995, 1998) and Milgrom, Roberts (1990, 1995) what we seek to do is verify if the returns to increasing internal R&D activity are non-decreasing in the level of firms' networking activities.

Actually, when a firm invests in R&D that involve skills, knowledge and competences, which the firm only partially owns, a joint cooperative effort, that involves other firms in the same area of businness, may increase the marginal returns associated with the R&D investment[5]. At this point, it is worth noting the interesting contribution by Carlaw, Lipsey (2002), who highlight a difference between complementarity relationships and externality relationships, within a wider notion of *technological complementarities,* of whose technological externalities are a subset, occurring when some of all innovation rents are not captured. What interests us for the following theoretical and applied analysis is the assertion that: " it follows that the existence of a technological complementarity is necessary but not a sufficient condition for the existence of a technological externality" (p.1310) and "there is gain even though the return on capital invested in innovation never exceeds the return on investing in existing technologies at any point in time" (p.1315).

In their frame, real externalities are a specific case possibly arising out of more standard complementarity links, when extra and not appropriable (partially appropriable) rents emerge with respect to the BAU situation. In other cases, links between firms are characterised by complementarities between technological factors that may replicate the market opportunity cost (BAU) and are fully appropriable, but cannot be defined as external spillovers. They note that a mere replication of (innovative) rents/opportunities is on the one hand lowest in ranking with respect to the creation of spillover externality, leading element of growth, but it is still positive since it has to be compared with a possible decrease of innovation capacity and performances[6].

What we are interested in is empirically verifying if a complementary relation exists between firms' internal R&D activities and networking activities. In a comparative statics analysis, we are particularly interested to discover in the presence of which firm-specific factors, such as product markets or firm dimension, this relation holds.

It is worth noting that our aim is different from those works which concentrate their analysis on the knowledge spillovers on firms' innovation activity. Actually the concept of complementarity is different from that of positive spillover. The latter occurs when the overall benefit from some activity (rather than the returns of increasing that activity) is increasing in the level of another activity (Roberts, 2006). Differently from spillover, hence, if a relationship of complementarity is found between two activities of a firm, this

[5] On the other hand, as noticed in Fritsch, Lukas (2001), since R&D cooperation could be considered by the firm a way of outsourcing parts of the innovation process to increase its degree of specialization, networking and internal R&D activities might show a substitution relation.

[6] In their words, there would be major gains from technological change even if the returns of capital invested in innovation never exceeded the returns of investing in existing technologies so that there were neither externalities nor positive changes in TFP. Though frameworks are different, mainly given on that we set a discrete framework of analysis, an analogy may be found between, on the one hand, increasing returns-externality/extra rents and, on the other hand, constant returns/no externality/BAU rents.

implies that if one of the two activities is increased, it will be more attractive for the firm to increase the other activity too, and system effects arise, with the whole being more than the sum of the parts. This has obvious implications on both firms' strategies and policy decisions. Actually, when two or more activities of a firm show complementary relations, firm and policy efforts should be targeted toward all the activities, since it is possible that improving only one of them would even worsen the firm's performance[7].

2. Testing complementarity between R&D and networking

2.1 Concepts and methods

The aim of this section is to provide a methodological framework to support the empirical test on complementarity between firms's networking and R&D investments.

Since both R&D and networking are measured in our dataset as discrete choice variables[8], we study complementarity between these two activities, through the properties of supermodular functions.

Following Topkis (1995, 1998), Milgrom, Shannon (1994), Milgrom, Roberts (1990, 1995), we say that a set of variables $x \in X \subseteq R^n$ is complementary if a real-valued function $F(x)$ on a *sublattice* $X \subseteq R^n$ is supermodular in its arguments[9].

In our case, if R&D and networking are complements, a firm's objective function must be super modular in these two variables.

Specifically, we consider a firm's average productivity function (AP_j) as the objective function and we focus on just two of the many decisions that can affect the firm's productivity function: R&D and networking:

(1) $$AP_j = AP_j(R, N, \theta_j) \qquad \forall j.$$

The problem of firm *j* is to choose a set of investment strategies for R&D (R) and networking (N), which maximizes its average productivity function. Complementarity between R&D and networking may be analysed by testing whether $AP_j(R, N, \theta_j)$ is supermodular in R and N. θ_j represents the firm's exogenous parameters. Actually, a firm operates in an environment which is characterized by exogenous parameters (such as product market) and one can be interested in how different values of the parameter θ may imply different instances of the firm's decision problem, and hence different optimal choices and

[7] On this subject, it is worth quoting the example described in Milgrom, Roberts (1995, p. 194): "General Motors, once the most successful of mass producers, spent some $80 billion during the 1980s on robotics and other capital equipment normally associated with the new methods. It did not, however, make any serious adjustments in its human resources policies, its decision systems, its product development processes, on even in its basic manufacturing procedures. Either it failed to see the importance of making these complementary changes or else, it was unable to make the changes that were required on these dimensions. The result was that those billion dollars were largely wasted.".

[8] A firm either invests in networking or it does not, and either invests in R&D or it does not. R&D is originally elicited as a continuous expenditure variable. We use the R&D dummy for the purposes of discrete based analysis of complementarities.

[9] a *sub lattice* $(X, \geq)$ is defined as a set X, with a partial order $\geq$, such that for any $x', x'' \in X$ the set X also contains a smallest element under the order that is larger than both x' and x'' and a largest element under the order that is smaller than both x' and x''. Let $x' \vee x''$ denote the smallest element that is larger than both x' and x'', and let $x' \wedge x''$ denote the largest element that is smaller than both x' and x''. A real-valued function F on a *sublattice* X is supermodular in its arguments, if and only if: $F(x' \vee x'') - F(x') \geq F(x'') - F(x' \wedge x'') \quad \forall x', x'' \in X$, that is, the change in F from x' (or x'') to the maximum $(x' \vee x'')$ is bigger than the change in F from the minimum $x' \wedge x''$ to x'' (or x'): having *more* of one variable *increases* the returns to having *more* of the other.

average productivity of the firm. The maximization problem is the same for all the firms, but, since each firm is characterized by specific exogenous parameters (θ_j), the AP function may result as supermodular in R and N for some firms, but not for others.

Our aim is to derive a set of conditions that can be used in empirical tests, to verify whether complementarity between R&D and networking is confirmed by the data, or in which specific circumstances (firm-specific exogenous parameters) complementarity holds.

We can consider each of the two choices about R&D and networking as binary decision variables. So, if a firm chooses to invest neither in R&D, nor in networking, we have $R = 0, N = 0;$ in this case the element of the choice set is $\{00\}$. If a firm chooses to invest both in R&D and in networking, we have $R = 1, N = 1$, and the element of the choice set is $\{11\}$. Including also the mixed cases, we have four elements in the choice set: $\{\{00\},\{01\},\{10\},\{11\}\}$.

From the definition of complementarity through supermodularity, we can assert that R and N are complements and hence that the function AP_j is supermodular, if and only if:

(2) $$AP_j(11,\theta_j) + AP_j(00,\theta_j) \geq AP_j(10,\theta_j) + AP_j(01,\theta_j),$$

clearly equivalent to:

(3) $$AP_j(11,\theta_j) - AP_j(00,\theta_j) \geq \lfloor AP_j(10,\theta_j) - AP_j(00,\theta_j)\rfloor + \lfloor AP_j(01,\theta_j) - AP_j(00,\theta_j)\rfloor,$$

that is, the changes in the firm's average productivity when both forms of investment are increased together are more than the changes resulting from the sum of the separate increases of the two forms of investment. Actually, the increases in AP due to an increase of both R&D and networking from $\{00\}$ to $\{11\}$ are more (or at least equal) than the sum of the increases in AP due to separate increases of R&D and networking from $\{00\}$ to $\{10\}$ $(\{01\})$.

Inequality (3) can also be written as:

(4) $$AP_j(11,\theta_j) - AP_j(01,\theta_j) \geq AP_j(10,\theta_j) - AP_j(00,\theta_j).$$

Increasing one of the two forms of investment (for instance R&D) increases firm's average productivity in a wider way if the other form of investment also increases: increases in AP due to an increase of R from $\{00\}$ to $\{10\}$ are less (or at least equal) to the increases in AP due to increases of both R and N from $\{01\}$ to $\{11\}$.

Summing up, complementarity between the two forms of investment (R&D and networking) exists if the AP_j function is shown to be supermodular in these two variables and this happens when one of the above inequalities is satisfied[10].

2.2. Data and context

[10] Since complementarity is symmetric (having *more* of x' *increases* the returns to having *more* of *x''*, as well as having *more* of *x''* *increases* the returns to having *more* of *x'*), when the binary decision variables are two, the relevant inequality is one. In the empirical analysis below the inequality $AP_j(11,\theta_j) + AP_j(00,\theta_j) - AP_j(10,\theta_j) - AP_j(01,\theta_j) \geq 0$ will be tested, clearly equivalent to inequalities (1)-(4).

The applied analysis is based on a dataset stemming from a comprehensive study concerning a Province of the Emilia Romagna Region, in Northern Italy[11]. Emilia Romagna is an area of Northern Italy characterised by a high density of industrial districts, and shows a very high level of per capita GDP (around 27,000€ in 2003).

We support the perspective that micro-data at firm level are necessary for the kind of theoretical and applied analyses we deal with. Surveys are therefore the only way to pursue such a research direction.

Surveys have been conducted on industrial and market-service firms with at least 20 employees and which have establishments in the Province, thus excluding agriculture and public administration. We initially identified 436 firms, which were disaggregated by sectors (metalwork, market services and other industries: textile-wearing articles, food products, chemical products, engineering and energy) and size (20-49, 50-99 and more than 99 employees, corresponding to small, medium and "large size" firms). Building on those 436 firms (the universe), a random sample of 250 firms was selected (57% of the universe).

A first wave of data was collected during 2003 by direct interviews to managers of human resources at the central offices of the firms. We ended up with 243 filled questionnaires out of a total population of 436 firms in the Province. A second consequential survey, which is the root of this study, was carried out in May 2005, administering a shorter but focused questionnaire by telephone. This questionnaire elicited information on performance trends (productivity, profit, turnover, employment)[12] over two periods (2000-2002 and 2003-2004), high-performance practices, outsourcing, training, R&D and technological innovation, and ICT dynamics. Within part of the questionnaire devoted to innovation, a specific part was dedicated to networking. We asked whether firms had voluntarily experienced networking activities concerning technological innovation development (broadly defined), with respect to clients/subcontractors, universities and research centres, other competitor firms. If networking occurred, it was specified whether it concerned both agents within the local area and outside, or only within/only outside. On this basis we may thus exploit different proxies of networking in a discrete framework: networking in general terms, networking with specific agents, geographical specificity.

Most of this data was elicited over 2000-2004, either as trends (i.e. adoption of some typology of innovations over the period) or as annual mean values (i.e. R&D and training expenses). We addressed the same 243 firms which joined the first survey: after dropping firms which closed down and others which refused to be interview, we ended up with 147 firms. This is the number of firms forming our integrated final dataset. The sample is highly representative of the population. Tab.2a-d show population and sample

[11] The area was selected as case study given the support provided to the applied study and the surveys by the Province of Ferrara, the public territorial institution that manages most of innovation, labour and training policies at local levels.

[12] We chose to elicit and use performance trends as stated by managers, instead of official balance accounts data, since the latter are hardly available for all interviewed firms and moderately reliable, regarding SME, especially under the threshold of 100 employees. This is a critical point for applied research in SME contexts. Nevertheless, we note that recent works dealing with analyses concerning other areas of Emilia Romagna Region (Antonioli et al., 2004, 2007) interestingly show that the degree of statistical correlation between official balance accounts and survey information on firm performance are high, at around 0.7-0.8.

Data gathering problems characterises also different contexts. An example is provided by the recent study by Dearden et al (2005), who exploit official survey data on training to measure the impact on productivity levels. They observe that the only publicly available firm level panel data in the UK is a sample of 119 firms with basic training information. This confirms the absolute need, if we aim at studying firm behaviour in details, to exploit information deriving from direct survey conducted on the field, with the associated pros and cons.

firms of 2003 and 2005 surveys. Tab.3a-d show descriptive analysis of the main variables of present relevancy (R&D, networking), presenting general figures and disaggregated figures by sector and size.

2.3 Empirical model and methodology

We may affirm that three methodologies exist for empirically assessing the complementarity hypothesis. The first analyses complementarity by studying the correlation of two or more variables, controlling for other factors. A usual way of carrying out such a test is by setting a bivariate or multivariate probit model, where complementarity arises if the null hypothesis of no correlation between the residuals of the two or more probit regression is rejected. In this case the variables under scrutiny are the dependent elements of the empirical model (Galia, Legros, 2004b; Laursen, Mahnke, 2001).

The second approach is defined as a reduced form approach (Arora, 1996): the analysis of complementarity is carried out by focusing on the effects of two factors, and on their correlation. It is typically implemented by setting interaction terms. The limit is the focus on only two elements (Athey, Stern, 1998).

The third approach is the one which allows grater flexibility and it is currently the most widespread. We may call it the productivity approach: it can deal with two or more factors on which the hypothesis is tested, and it is based on the estimation of an objective function, either a production function or an innovation function. Within it, two ways can be highlighted. The most common one is assessing the hypothesis by testing the significance of interaction variables, which capture the complementarity effect (Laursen, Foss, 2003, Brynjolfsson, Hitt, Yang, 2002 among the others). The most recent and highly flexible way is to analyse complementarity within a discrete framework where, given two or more factors, the hypothesis is tested by evaluating the effects of all possible states of the world, associated with complementarity or substitutability[13]. This paper exploits both methods: we first analyse complementarity by using interaction terms and then by exploiting the full set of states of the world arising from couple of drivers (i.e. networking and R&D). We use (average) labour productivity (value added/employment) trends (as elicited from firm managers) for 2003-2004 as the main dependent variable, a variable ranging from 0 to 1[14].

The empirical model is a reduced form for productivity, of the form:

$$PROD_{i,t} = \beta_0 + \beta_{1,t}(\textit{structural firm features: size and sector as main controls}) + \beta_{2,t/t-1}(\textit{R\&D variables}) + \beta_{3,t}(\textit{Networking variables}) + \beta_{4,t}(\textit{other innovation variables: ICT, organisational innovations, outsourcing}) + e_i$$

[13] Other works which address the issue of heterodox environments, mainly using case study analysis or simulation approaches, are among others, Langlois (2002), Kauffman, Lobo, Macready (2000), Marengo, Dosi (2005). Complementarity is nevertheless addressed and studied from a quite radically different angle, with a conceptual focus on technological uncertainty, systemic evolution, and dynamic capabilities of firms. The assessment of causal links between input and ouput variables is not the aim of such varied streams of research.

[14] In addition, in the analyses of sections 3.1.1 and 3.2.2, output innovation-related dependent variables are also exploited, being primarily productivity and also output innovation (product and process) the two objectives of R&D and networking efforts. A sort of 'knowledge production function' is adopted as reference (Griliches, 1979). The knowledge production function expresses the relationship between innovation output and innovation inputs within the 'conceptual' framework of a production function. In the case of productivity, we are prevented from using a more standard but not always necessary production function approach, since we do not possess reliable data on capital stocks for those firms.

Where *PROD* represents the performance of firm *i*, and e_i the error term with usual properties. β_0 is the constant term, $\beta_{1\text{-}4}$ the set of coefficients associated with groups of explanatory variables, where (*t*) stands for a variable whose trend is ascertained over 2004-2003 and (*t*-1) over 2004-2000. Tab.4 presents descriptive statistics for main dependent and independent variables.

When estimating regressions with indexes ranging between 0 and 1, we face a limited but continuous variable. We deal with *fractional variables* (Papke, Woolridge, 1996), continuous but limited. It is possible to affirm that there is not an "optimal" econometric model for studying fractional variables. Although OLS estimates in this case may suffer from the same distortions characterising the use of linear models for binary variables, one-limit or two-limit Tobit models are not a panacea, and often it is possible to verify that estimates deriving from OLS, OLS based on (log) transformations (when this is possible given the observed "0s") and Tobit do not differ significantly as far as coefficient signs and "relative" statistical significances are concerned (Pindyck, Rubinfeld, 1991), although coefficient "levels" are different across models. Since the aim is not (here) the estimation of elasticity, this may be considered a less severe flaw. Thus, OLS corrected for heteroskedasticity is used as an econometric tool for estimation.

It is worth speaking briefly about the discrete based regression analysis of complementarities. We specify regressions entering the four dummies associated with the potential states of the world: 00 (no networking, no innovation[15]), 10 (only networking, no innovation), 01 (no networking, only innovation), 11 (both networking, and innovation), where *one*, as said, means presence and *zero* the absence of the productivity input in a specific firm.

From a statistical perspective, each state of the world, is included in the productivity regression as a sort of dummy. Such dummies are like constants; the model is thus a "without constant" specification, instrumental to estimate the set of parameters for carrying out the test. We need to include all state dummies in order to recover the full estimates of coefficients and variance / covariances.

Going directly to the definition, we may recall from section 2.1 that complementarity holds if and only if [b1+b2-b3-b4≥0]. Empirically speaking, b1 and b2 are the estimated parameter linked to "complementarities states" (i.e. (00), (11)), while b3 and b4 are associated with the other states ((10), (01)). The reasoning surrounding couples of input drivers (bivariate analysis) leads to a statistical framework where the complementarity hypothesis is the one expressed above. A *one sided t test* is thus applicable for the present investigation in order to assess the degree of complementarity[16]. The null hypothesis is the complementarity state under a non-strict inequality (≥0)[17]; we thus test complementarity in a non strict framework. Only if a negative value is observed below the defined threshold (e.g. 5%, 1%) we may conclude and reject the null at the specified significance level.

[15] See tab. 6b for a description of the complete vector of innovation and networking discrete (dummy) proxies used here and tested by couples (i.e. networking and R&D, networking with universities and R&D, networking with universities and innovation ouput, etc..).

[16] We note that one-tailed tests make it easier to reject the null hypothesis when the alternative is true. A large sample, two-sided, 0.05 level t test needs a t statistic less than -1.96 to reject the null hypothesis of no difference in mean. A one-sided test rejects the hypothesis for values of t less than -1.645. Therefore, a one-sided test is more likely to reject the null hypothesis when the difference is in the expected direction.

[17] More specifically, in this case we have three possible outcomes: if the null is not rejected the hypothesis of complementarity holds in the ≥0 form, which is consistent with the theory (Milgrom, Roberts, 1990, 1995; Topkis, 1995, 1998). A value higher than 1.645 on the positive sign will lead to a strict complementarity assessment (b1+b2-b3-b4 >0), while a negative value lower than the defined threshold (e.g. 1,645, or a 5% tail, within the one tail framework) will lead to a rejection of the null.

The next sections present and comment on empirical outcomes drawn from regression analysis. We first preliminary investigate the main drivers of productivity, then we test complementarity by using interactions, and finally we show the evidence concerning the full assessment of complementarity in a discrete setting.

3. Empirical evidence

3.1 Preliminary analysis: main productivity drivers

As far as structural firm features are concerned, a clear size effect emerges. Size is a crucial and confirmed explanatory factor. Then, productivity is also correlated with metalwork manufacturing firms, although statistically less significant across specifications, but not to market service firms, also confirming an expected result.

Focusing on main productivity drivers, expenditures per employee in R&D and informal training emerge both as significant factors, impacting on productivity with the expected positive effect. This is in line with other evidence on Sweden and France: R&D and training exert significant effects on productivity which may be partially country-specific; nevertheless, no evidence is found in favour of positive interactions between these two forms of capital (Ballot, Fakhfakh, Taymaz, 2001). Furthermore, the training coverage variable, when included separately, is associated with a positive significant coefficient.

We are aware that endogeneity may affect data when using R&D and formal training per employee, elicited as annual trend values over 2002-2004, as covariates for explaining productivity. We thus estimate regressions for R&D and training expenses in order to recover predicted values/residuals and consequently carry out regression based tests for endogeneity[18]. According to some contributions on Italian industrial districts (Brusco *et al.*, 1996; Cainelli, Zoboli, 2004; Cainelli, Nuti, 2002), this kind of formal and informal networking relationship, as well as information spillovers, may be interpreted as 'quasi-fixed factors of 'production', in any case slow evolving over time. This means that those variables might be considered as pre-determined factors, exogenous with respect to district firm innovative activity unless we focus on long run dynamics[19].

We use our indexes related to organisational innovations, high-performance practices and workforce features (i.e. tenure, stock of short term employees, skill level) as instruments for training, in addition to basic structural controls, while we exploit the networking index, the ICT composite[20] index and the high-performance practice index as instruments for R&D. It is worth noting that the former (first stage) regression, specifying training expenses as the dependent variable, shows that size, international market turnover share, workforce skill level and the two indexes of high performance practices and organisational innovations are all firm specific elements which are positively and significantly correlated with training.

The regression for R&D instead shows, in addition, the potential role of networking as a factor correlated with R&D intensity in firms. On those grounds, endogeneity is tested by a *t* test on the coefficient

[18] See Wooldridge (2002, pp. 90-92) for a comprehensive discussion on "two-stage least squares" and for a clear presentation of regression-based form (omitted variable approaches) of the Hausman endogeneity test (p.118).
[19] Similar considerations are put forward by Brynjolfsson *et al.* (2002) for organizational capital.
[20] The choice of the set of instruments is driven by the low correlation between ICT, organisational innovation, high-performance practices and workforce characteristics with respect to productivity. Most of those elements are instead related to training and R&D. In our case, thus, ICT and organisational innovations seem not to directly affect firm performances, but indirectly, through a correlation with other drivers.

of such obtained fitted values in the second stage heteroskedastic robust regression: for training, the *t* test shows that the null hypothesis of exogeneity is not rejected by data (we observe a very low *t* ratio for the predicted value coefficient). As far as R&D is concerned, the same outcome emerges[21]. This is a signal that our cross section dataset, given the overlapping but not coincident periods of productivity and drivers, may be not affected by endogeneity. We recall that if the aim is analysing networking activities and firm spillovers in general, panel structures are rare if not impossible, given the informal, intangible and survey-based nature of networking activities (Huselid, Becker, 1996; Cassiman, Veugelers, 2002).

To conclude with the analysis of drivers, we add evidence on further explanatory factors of productivity.

Other significant factors impacting on productivity trends, included incrementally in other specifications, are: (i) the dummy capturing whether or not firms have adopted product/process technological innovations over 2000-2005, (ii) the index of networking activities in the realm of innovation activities[22]; and, interestingly, (iii) the dummies associated with the outsourcing of accessory and core activities show, respectively, a positive and a negative plausible sign of coefficients.

Instead, ICT dynamics, high performance practices, like TQM, QC, JIT, and synthetic indexes of organisational innovations do not *directly* exert significant impact on 2003-2004 productivity trend[23] (see tab.5 for a summary of main regression outcomes). R&D, training, networking, technological innovation and outsourcing arise, to a greater or lesser extent, as forces behind the productivity trend. The consequential analysis of next sections will focus on complementarities based on such premises.

We then now focus on the specific relationship of R&D with networking dynamics, first testing interactions, and secondly assessing R&D/networking relationships in a discrete setting as described above.

3.2 Testing complementarity between R&D and networking activities in a discrete setting

A full assessment of complementarity is performed by creating four states of the world for each analysed couple of drivers. All drivers should be discrete or made discrete. Regressions are estimated inserting those states, and the usual control variables (firm structural features). The test is implemented as a *t* test on the estimated coefficients for the 4 state variables.

Overall, then, 66 tests are carried out. The factors on which complementarity is analysed are R&D and networking discrete indexes. R&D is made discrete both by using a dummy taking value one if R&D>0 and a dummy taking value one if R&D expenditures of the firm are higher than the average figure. Networking is analysed by means of six discrete proxies: general presence of networking (58% of firms), networking with Research institutions and Universities, networking with clients and suppliers, networking with other competing firms, networking with firms within the boundaries of the local area (province), networking in the form of outsourcing activities.

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[21] Exogeneity is not rejected both using predicted and residuals in the second stage regression. Then, it is confirmed for both productivity and overall performance 2003-2004 levels (including also profitability, turnover, and investments).

[22] Networking is defined with respect to cooperation activities regarding other firms (clients, suppliers, competitors) and institutions (university). The index varies between 0 and 1 and captures the intensity of networking activities by firms.

[23] As far as high performance practices are concerned, we could test whether the introduction of TQM, QC, JIT, and team working *before* 2000 had an impact on 2003-2004 productivity, allowing (at least) four years lag causal response between the driver stimulus and the effect on performances. Using dummy variables for adoption before 2000, for each practice, we do not then observe any statistical significance.

Summing up, twelve combinations of R&D/networking are scrutinised. Such combinations are tested for four different objective variables: productivity, as above, as the main factor. Then, the index of technological innovation adoption and two dummies for process and product innovation adoption are also used. Those mentioned examined links account for 48 tests on complementarity. The remaining 18 tests are carried out using productivity and the index of technological innovation adoption as objectives (see Mohnen and Roller, 2005, for an analysis on technological innovation and complementarities). R&D, networking (general dummy proxy) and ICT/organisational innovations are selected as drivers, in order to further test whether networking, R&D and also 'organisational innovation inputs' are complements, with respect to firm performances.

We summarise empirical evidence distinguishing between the analysis which refer to (1) productivity, (2) innovation output, (3) process and product innovation separately taken[24].

First, we observe that with regard to productivity (21 tests overall) strict complementarity (*t* ratio higher than 1.645, a 5% probability mass in the right tail) is never found. We find three cases where the test would pass at the lower 1.245 statistical threshold (a 10% probability mass in the right tale): R&D/networking with clients and suppliers, R&D/networking with non-local firms (both cases with R&D=1 if higher than average)[25], ICT/networking. Nevertheless, in no case would the test lead to a negative and statistically significant value (though some negative values are observed), thus rejecting even non strict complementarity.

Secondly, when using the index of ouput innovation as the objective, we instead find two cases where the null $b1+b2-b3-b4 \leq 0$ would be rejected (substitutability situations)[26] and one case where strict complementarity arises at 10% (networking/ICT). All other 18 cases refer to *non strict complementarity* as defined here [27].

Finally, as far as product and process innovations are concerned, we highlight six cases (out of 12) where complementarity is rejected by our data when focusing on process innovation, and one case of strict complementarity (R&D/networking with non local agents) when testing complementarity with respect to the adoption of product innovation. Overall, complementarity seems to play a role with regard to product innovations, which are, for the sectors studied here, more involved by innovation radicalness (Dahlin, Behrens, 2005)[28]. Regarding process innovation, instead, complementary relationships appear to characterise R&D and networking dynamics to a lesser extent. Firms rely either on internal R&D or on networking, if they adopt process innovation (the 54% of firms).

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[24] Tab. 6b presents a synthetic sketch of results. Regressions are not presented for brevity and because instrumental to the complementarity tests. They are available upon request.

[25] Though we cannot conclude that overall the dummy R&D=1 higher than average structurally changes test results with respect to R&D=1 if R&D>0.

[26] R&D/networking with non local agents; R&Dav/ORGdummy.

[27] Those include R&D and outsourcing, which present complementarity in all tested regressions, in line with the analysis of Mol (2005), who underlines a relational perspective when studying outsourcing in R&D intensive industries, showing that firms in R&D intensive industries may have increasingly started to rely on partnership relations with outside suppliers.

[28] Conceptually, we mean that in terms of radicalness intensity, product innovation is deemed relatively more radical than process innovations by many authors (Langlois and Robertson, 1992, Teece, 1986), insofar product innovations characterise more the embryonic phase of innovation development while process innovation the mature stages of development. Both can in any case share radical and incremental features. In addition, there are fields, like the environmental innovation one, where process innovation tend to be more radical oriented than product innovations in terms of efficiency improvements. With regard to our data, we elicit both process and product innovations; the former is adopted more frequently, as usual in those local systems, the radical ones are also more frequent within process innovations, but with a short gap.

To sum up, with respect to productivity, complementarity holds, with some signals of "strictness" in the examined empirical link[29]. From the analysis on innovation outputs, some signals of possible non-complementarities arise, confirming the outcome of section 3.2. Looking more specifically at diverse adoption of process and product innovations, heterogeneous results arise. This highlights the need to investigate complementarity in detail with respect to the firm performances of interest. Along the innovative and value chain "innovation input → firm performances: innovation output → productivity", non-homogenous relationships of complementarity could characterise different levels/steps of the chains and/or different assets/productive inputs. The picture, as it arises here, is possibly patchy. Within a general evidence of complementarity links holding for SME performance drivers, some links of complementarity in its strictest sense here defined, and also some elements of substitutability links emerge. On this more detailed basis, we may then assess with more specificity where, on average (for the average firm), potential negative criticalities and potential positive dynamics are.

4. Conclusions

The paper addresses the relevancy of networking activities and R&D as main drivers of productivity performance and ouput innovation, for (SME) firms playing in a local economic system. Original recent survey data for manufacturing and services are exploited in order to test complementarity links mainly between R&D and networking, with respect to productivity and ouput innovation performances. The picture we draw out of our data analysis is the following. At a more conceptual level, complementarity in its strictest sense rarely arises from the data, though it is present in some cases. Some "ice stones" of strict complementarity evidence in fact arise with respect to R&D/general networking and R&D with some specific networking activities. Overall, R&D and all networking specifications we use are characterised by a non-strict complementarity nexus which, by analogy, may be associated with constant returns to scale. Process innovation is instead the realm where effective non-complementarity is more frequent. Compared to other studies more focused on large firms, the weaker, though present, evidence on complementarities among productive inputs, could be related to the average size of firms in SME environments. That is why the analysis of networking as an alternative way to achieve scale economies plays a crucial role, and the evidence between networking and innovation should be taken as key information for management and policy making.

Our observed local economic system is characterised by low average figures on innovation and networking. Even observing a local economic system which is located in a rich European region like Emilia Romagna and which is representative of the average system with respect to Italian economic dynamics, 60% of firms declare not to invest their own money in R&D, and 42% say that they do not collaborate with either firms or research centres. A limited number of firms drive the whole system by high innovative dynamics and performances. The picture is thus quite heterogeneous, in line with most local systems where small firms are predominant. As shown, networking and R&D weaknesses are more visible in small firms.

[29] Complementarities may also be aimed at maintaining the current innovation dynamics and thus performance. This is to be considered a successful outcome as well (Carlaw e Lipsey, 2002). We may affirm that strict complementarity relationships can be certainly associated with increasing returns to scale, generating extra rents and externalities with respect to the BAU scenario, but it is consistent also with constant returns to scale, where the market opportunity cost is merely replicated, and real externalities are not emerging.

First, R&D is a main driver of innovation and productivity, even without networking. This may signify, in association with the evidence on complementarity, that firm expenditure on R&D is a crucial driver for performance. The complementarity with networking is a consequential step: according to the conceptual framework depicted in this and other quoted works, networking is an external asset which is, totally or partially, a public good (not protected by formal appropriable agreements), or the public element of an impure public good, where R&D is the private factor. Thus networking by itself cannot play a role in stimulating productivity and innovation. It can be a complement factor in situations where cooperation and networking are needed to achieve economies of scale and/or to merge and integrate diverse skills, technologies and competencies.

Networking, as a partial public good, nevertheless probably emerges if stimulated by a *sufficient amount* of the "private" R&D element (internal source, explicitly excluding public funds). This is probably the reason why we observe a stronger overall evidence in favour of complementarity when analysing links in a discrete setting, which by definition distinguish and separate out different firms as "0" (below a threshold) and "1" (over a threshold). This is a main finding of the paper.

This theoretical reasoning, associated with our and other empirical evidence, is plausible with the lack of investments in R&D and networking by firms in local economic systems in the current economic scenario. As a consequence, networking is in itself probably not a source of innovation. Networking cannot exist without R&D acting as primary engine. We reject theories asserting that networking stems from a territorial atmosphere that produces networking and innovation as by products or more or less spontaneous outcomes. The territorial atmosphere rich in spillovers, externalities and voluntary networking is favourable to competitiveness because it is intense in innovation. R&D and other innovation oriented investments create the pillars of innovation, networking and performance in local economic systems where SME prevail. The virtuous circle, we believe, starts from innovation investments, favoured by market (opportunity costs) and public (subsidies, regulations) driving forces. The metaphors of civic virtue and favourable socio economic atmospheres characterising local areas are representing a concrete phenomenon, but observed from an incorrect angle, or at least not useful for providing information on how increasing competitiveness in this currently fragile local systems.

On the basis of the mentioned average lack of investments in R&D and networking, complementarities are shown with respect to those drivers but are, to a greater extent, not exploited, given insufficient investments in R&D and, consequentially, a very limited development of networking. With R&D as main driver, relatively larger firms are probably self sufficient in local economic system, though networking is still relevant for them at the level of interrelationships with other large firms operating in other national and non national areas. The majority of SME is instead lacking both of R&D and networking. Large firms' development is not sufficient to structurally change the dynamic of local system needing new competitive advantages. This is the current challenge for many European local systems where SME prevail. Though networking is certainly crucial for SME, the first step is likely to be R&D, which then favours and stimulates virtuous dynamics. This is consistent with a theoretical framework where R&D and networking are linked by an impure public good structure: the lack of networking and the lack of R&D are two sides of the same coin; networking is necessary, potentially generating crucial innovation exchanges, but probably not sufficient for a full upturn in terms of competitive advantages of single agents and of local economic systems.

R&D is the key that is likely to stimulate a virtuous circle of investments in R&D and networking. This means that, given the current typical small firm environment of the Italian local economic system, a few number of large and medium firms (3% of firms employ more than 50 workers) is self sufficient in terms of R&D investments (and even networking, within and outside the local system). The remaining bulk of agents has to increase investments both in formal R&D and networking, in order to create innovation by formal and informal instruments, and, more importantly, to generate non-appropriable asset specificity involving internal R&D and external networking dynamics. The menu of institutional alternatives is large, and both internal firm resources and networks, of which there are several kinds, can be successful, growth-promoting adaptations to the competitive environment (Robertson, Langlois, 1995).

From a policy perspective, we may provide two suggestions. Our evidence suggests that R&D may be a single main driver of performance. Since R&D expenditures are associated with firm size, a specific policy sustain, under the general umbrella of R&D subsidy intervention justified by market failures, is to be directed towards firm enlargement. After a certain threshold firms have the necessary strength to increase R&D expenditures, that may act as an autonomous performance driver for firms. The size effect is nevertheless non linear: if it is true that in absolute levels R&D is increasing with size we may also find inverted U-shapes when examining the correlation between R&D per employee and size. In any case, a critical threshold, say 100 employees, is necessary for experiencing a sufficient base of R&D as driver of innovation and performance.

Finally, but not least important, for the majority of firms still remaining under a critical size threshold, policy incentives should be directed to R&D in connection with networking, through which a virtuous circle may arise. It is worth noting that it is not networking as such the main engine. In our framework and evidence, we argue that networking is necessary to achieve economies of scale for SME enterprises. Nevertheless, incentives should still target R&D, since it is R&D that stimulates the public component of networking, then providing the necessary basis for a co-causation effect. It is thus important to stimulate initial efforts on R&D for small firms, that, given it is unlikely that they possess internally by themselves all the innovative capacities and competencies, will join other agents in cooperative efforts where complementarities relationships emerge.

Managers and policy makers should be aware that in order to exploit asset complementarity, possibly transformed in competitive advantages, both R&D and networking are to be sustained and favoured. Nevertheless, R&D should probably be the first target, by means of regional/local policies, if positive externalities are deemed to exist, and the process of size enlargement, even possibly stimulated by fiscal instruments and subsidies. As recently noted by Blanes, Busom (2004) for Spain, it is necessary to identify those R&D projects where the gap between private and public returns is the highest. Being networking a relevant "public part" of our model of reference, that generates additional social returns in a R&D-networking interplay, one criterion for selecting R&D subsidy may be the intensity of networking associated with R&D expenditures. This may be a way to attract new smaller firms since, as found by the cited authors, size seems still to represent a barrier, even for participating in R&D programs even at a policy level, a transparent correlation between R&D and networking when funding innovation could help virtuous dynamics to emerge in local systems.

Networking elements are crucially linked to innovation dynamics; it is innovation that explains and drives networking, and not the often claimed mere existence of local spillovers or of a civic associative culture in the territory. Such public good factors exist but are likely to evolve with and sustained by firm innovative dynamics. According to the theoretical reasoning, we should give a primary role to R&D, which then drives networking for R&D effort which needs, to go beyond BAU scenarios, a networking of competencies, innovation efforts, and skills. R&D and networking are thus complementary under this framework.

The evidence on complementarity is certainly dependant on: economic sector, economic system features (firm size), intensity of innovation and networking. The final answer is provided, as often in the literature dealing with innovation and firm performance, by specific case studies on different realities. The full puzzle is then drawn out following a sufficient amount of research. Though the applied contributions on complementarities have been increasing, it is probably needed some more effort in order to achieve a more comprehensive assessment. We thus suggest further research, mainly on the complementarities between tangible/intangible assets, among intangible assets and, quantitatively speaking, between intangible but quantifiable asset (R&D) and intangible not quantifiable assets (networking), which require a strong effort in data collection and treatment, mainly at firm microeconomic level.

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Tab.1 – Main recent empirical contributions dealing with complementarity

Paper	Performance	Innovation activities on which complementarity is tested	Data/country
Caroli, van Reenen (2001)	PRODUCTIVITY	Skill, organisational innovation/change	Panel/UK
Bresnahan, Brynjolfsson, Hitt (2002); Brynjolfsson, Hitt, Yang (2002); Brynjolfsson, Hitt (1997, 2000, 2003)	PRODUCTIVITY	HRM, organisational innovation/change, skill, ICT	Panel/US
Laursen, Mahnke (2001)	*	High performance practices, HRM	Cross section/Denmark
Laursen, Foss (2003)	Product and process innovation	Organisational innovation/change, HRM	Cross section/ Denmark
Lokshin, Carree, Belderbos (2004)	PRODUCTIVITY	Techno-organisational innovation/change; R&D networking	Cross section/Netherlands
Galia, Legros (2004a)	Product and process innovation	Team work, training, HRM, organisational innovation/change	Cross section/France
Galia, Legros (2004b)	*	Innovation obstacles	Cross section/France
Guidetti, Mancinelli, Mazzanti (2006)	PRODUCTIVITY	General and specific training	Cross section/Italy
Cristini, Gaj, Leoni (2004)	PRODUCTIVITY	Organisational innovation/change, ICT	Cross section/Italy
Astebro, Colombo, Seri (2005)	PRODUCTIVITY	Automative technological technologies	Cross section/US
Mohnen, Roller (2005)	Innovation	Innovation obstacles	Cross section/ EU
Aral, Weill (2005)	PRODUCTIVITY	HRM, organisational innovation/change, skill, ICT	Panel/US

*the analysis sees hypothesised complementary variables as dependant variables in the model, not drivers of firm performance.

Tab.2a: Reference Population (number of firms): *Survey 2003*

	Size			
Sector	(<50)	(50-99)	(>99)	*Total*
Machinery/Metalwork	87	23	20	*130*
Other industries	83	22	26	*131*
Market services	87	35	53	*175*
Total	*257*	*80*	*99*	*436*

Tab.2b: Population (%)

	size			
Sector	(<50)	(50-99)	(>99)	*Total*
Machinery/Metalwork	19,95	5,28	4,59	*29,82*
Other industries	19,04	5,05	5,96	*30,05*
Market services	19,95	8,03	12,16	*40,14*
Total	*58,94*	*18,35*	*22,71*	*100,00*

Tab.2c: Interviewed firms (sample): *survey 2005*

	size			
Sector	(<50)	(50-99)	(>99)	*Total*
Machinery/Metalwork	28	10	7	*45*
Other industries	21	8	11	*40*
Market services	31	20	11	*62*
Total	*80*	*38*	*29*	*147*

Tab.2d: Interviewed firms (sample) (%)

	size			
Sector	(<50)	(50-99)	(>99)	*Total*
Machinery/Metalwork	19,05	6,80	4,76	*30,61*
Other industries	14,29	5,44	7,48	*27,21*
Market services	21,09	13,61	7,48	*42,18*
Total	*54,42*	*25,85*	*19,73*	*100,00*

Tab.2e: Interviewed firms (sample) (%), detailed sectors

	size			
sectors	(<50)	(50-99)	(>99)	*Total*
Other industries				
Other manufacturing industries	1,36	0,00	0,68	*2,04*
Textile	8,16	0,00	0,68	*8,84*
Food & beverages	1,36	1,36	0,68	*3,40*
Chemical	3,40	3,40	2,72	*9,52*
Construction/ Energy	0,00	0,68	2,72	*3,40*
Machinery/Metalwork	19,05	6,80	4,76	*30,61*
Market services				
Commerce	8,16	4,76	1,36	*14,29*
Banking	0,68	0,00	0,68	*1,36*
Other market services	12,24	8,84	5,44	*26,53*
Total	*54,42*	*25,85*	*19,73*	*100,00*

Tab.3a: Networking activities aimed at innovation: descriptive statistics

Networking activity	firms	% firms with networking over 2004-2000	With agents in the Province (%)	With agents outside the Province (%)
University	28	19,05	14,97	6,80
Research centres	15	10,20	4,08	7,48
Clients	33	22,45	8,84	18,37
Suppliers	42	28,57	11,56	24,49
Other competing firms	29	19,73	9,52	15,65
Other agents	13	8,84	-	-
No networking	62	42,18	-	-
Networking index (0-1, averaging the presence of networking activities)	Average: 0,181	-	-	-

Tab.3b: Networking activities aimed at innovation: descriptive statistics by size and sectors

Networking index (0-1)	size			
Sector	(<50)	(50-99)	(>99)	*Total*
Machinery/Metalwork	0,14	0,23	0,33	*0,19*
Other industries	0,09	0,27	0,24	*0,17*
Market services	0,16	0,24	0,14	*0,18*
Total	*0,14*	*0,25*	*0,22*	*0,18*

Tab.3c: Firms which has invested own resources in R&D (*excluding public funds*) in R&D over 2000-2004, by size and sectors

% firms with R&D >0	size			
Sector	(<50)	(50-99)	(>99)	*Total*
Machinery/Metalwork	0,46	0,80	0,86	*0,60*
Other industries	0,14	0,88	0,40	*0,36*
Market services	0,19	0,50	0,27	*0,31*
Total	*0,28*	*0,66*	*0,46*	*0,41*

Tab.3d: Technological innovation adopted since 2000 by elicited typology

Technological innovations	% of firms
1. Product radical innovation	12,93
2. Process radical innovation	16,33
3. Product incremental innovation	31,29
4. Process incremental innovation	44,90
5. Radical innovations	23,81
6. Incremental innovations	54,42
7. Product innovation	38,78
8. Process innovation	54,42
10. No relevant innovation adopted	34,01
Technological innovation index (0-1)	*Average: 0,265*

Table 4- Descriptive statistics of variables: dependent and independent variables

Variable	Typology and value range	Acronym	Mean value	Minimum and maximum values	Period of observation
Average labour productivity 2003-2004 trend	Continuous index (0-1); 0,5 value means a stable average productivity; lower than 0,5 a decreased, higher than 0,5 an increase	PROD	0,58	0,1	2003-2004
Controls					
Sectors: Services, manufacturing/metalwork, benchmark base: other industry	2 dummies	SERV, MANUF	0,42; 0,30		Elicited in 2005 survey
Share of revenue on international markets	Continuous index (0-1)	NAT-REV	0,14	0,1	Elicited in 2005 survey
Share of revenue from acting as subcontractor	Continuous index (0-1)	SUBCONTR	0,67	0,1	Elicited in 2005 survey
Firm size	2 dummies (50-99 employees, >100 employees) or alternatively number of employees	Size1, Size2, Size	110 employees	20; 2207 employees	2004 employment level
Innovation and training variables					
R&D expenditures per employee	Continuous	R&D-EXP	479€	0, 10000€	2000-2004
R&D positive expenditures	Dummy	R&D	0,41	0,1	2000-2004
R&D positive expenditures (taking value 1 if R&D is higher than average)	dummy	R&D-1	0,21	0,1	2000-2004
Index of technological output innovations (radical and incremental, process and product)	Continuous index (0-1)	INNOTECH	0,55	0,1	2000-2004
Adoption of process innovation	Dummy	PROC	0,38	0,1	2000-2004
Adoption of product innovation	Dummy	PROD	0,54	0,1	2000-2004
Formal training coverage (share of employees involved)	Continuous index (0-1)	COVER	0,39	0,1	2002-2004
Formal training expenditures per employee	Continuous	TRAIN-EXP	160€	0, 1458€	2002-2004
Presence of any formal training expenditures using internal firm sources (excluding public funding)	Dummy	TRAIN	0,63	0,1	2002-2004
Networking					
Networking index (summarising cooperative behaviour with private and public agents within and outside the local area)	Continuous index (0-1)	NETW	0,18	0; 0,83	2000-2004
Networking (any)	dummy	NET	0,58	0,1	2000-2004
University/ Research centres	Dummy	NET-RIC	0,25	0,1	2000-2004
Clients/Suppliers	Dummy	NET-CL	0,40	0,1	2000-2004
Other firms	Dummy	NET-OTH	0,20	0,1	2000-2004
Non local firms	Dummy	NET-OUT	0,15	0,1	2000-2004
outsourcing	Dummy	OUT	0,46	0,1	2000-2004
Other organisational variables					
High performance practices (TQM, Just in time, Quality circle, Team working) index	Continuous index (0-1)	HPP	0,38	0,1	2000-2004
High performance practices (taking value 1 if index is higher than average)	dummy	INNOORG	0,33	0,1	2000-2004
Labour related innovation index (on ten HRM practices; i.e. task rotation, formal evaluation)	Continuous index (0-1)	LAB-INNO	0,32	0,1	2000-2004
ICT index of adopted ICT-related innovations	Continuous index (0-1)	ICT	0,28	0; 0,76	2000-2004
ICT (taking value 1 if index is higher than average, core web ICT activities)	dummy	ICT1	0,50	0,1	2000-2004
ICT (taking value 1 if index is higher than average, extensive ICT activities related to production)	dummy	ICT2	0,32	0,1	2000-2004
Consultation with trade unions regarding innovation adoptions	Dummy	INDREL	0,26	0,1	2000-2004

Table shows the all set of variables used in econometric exercises. Acronyms are shown for all variables entering final specifications.

Tab.5- Productivity Regressions: main drivers

SIZE1	2,669***	1,960*	2,076**	2,546**
SIZE2	2,330**	2,970***	2,799***	2,515**
SERV	0,783	0,679	0,708	0,909
MANUF	1,483	1,626	1,847*	1,708*
R&D-EXP	2,416**	…	…	2,508**
TRAIN-EXP	3,261***	3,255***	3,247***	…
INNOTECH	…	2,081**	…	…
NETW	…	…	2,031**	…
COVER	…	…	…	3,539***
F test (prob)	3,34 (0,0006)	3,28 (0,0008)	3,23 (0,0009)	4,04 (0,0001)
Adj-R^2	0,138	0,135	0,132	0,172
N	147	147	147	147

Notes: Dependant variable is productivity trend 2003-2004; (PROD); OLS corrected for heteroskedasticity is used as estimation tool; the four states of the world are used in place of the constant term (not shown)).We recall coefficients should not to be interpreted as elasticities; the table shows t ratios and emphasises statistical significance of coefficients at 10%, 5% and 1% (*, **, ***) levels. Besides size and sector dummies, only significant controls are presented in this table. The variable SIZE when included in place of size dummies is significant at ***: overall fit is unaffected.

Tab.6a Complementarities and drivers interactions: econometric outputs

Dependant variable	*Variables on which complementarity is tested*	*comment*
PRODUC	R&D-EXP, NET	Interaction with positive sign but not significant, net dummy significant (+)
PRODUC	R&D-EXP, NETW	Interaction with positive sign but not significant, networking significant (+)
PRODUC	R&D-EXP, NET-CL	Interaction with positive sign but not significant, net dummy significant (+)
PRODUC	R&D-EXP, NET-RIC	Interaction with positive sign but not significant, net dummy not significant
PRODUC	R&D-EXP, NET-OTH	Interaction with positive sign but not significant, net dummy not significant
PRODUC	R&D-EXP, OUT	Interaction with positive sign but not significant, net dummy not significant
INNOTECH	R&D-EXP, NET	Interaction with negative sign and significant, net dummy significant
INNOTECH	R&D-EXP, NETW	Interaction with negative sign and significant, networking significant
INNOTECH	R&D-EXP, NET-CL	Interaction with negative sign and significant, net dummy significant
INNOTECH	R&D-EXP, NET-RIC	Interaction with negative sign not significant, net dummy significant
INNOTECH	R&D-EXP, NET-OTH	Interaction with negative sign but weakly significant, net dummy not significant
INNOTECH	R&D-EXP, OUT	Interaction with positive sign not significant, net dummy significant

Tab. 6b complementarities (R&D, networking, organisational innovation) tests in a discrete setting: outputs from productivity and innovation functions

Dependant variable	*Variables on which complementarity is tested*	*One sided T test (t ratio for the test)*
PRODUC	R&D, NET	1,14
PRODUC	R&D, NET-RIC	0,93
PRODUC	R&D, NET-OTH	-1,06
PRODUC	R&D, NET-CL	1,16
PRODUC	R&D, NETOUT	0,36
PRODUC	R&D, OUT	0,58
PRODUC	R&D-1, NET	-0,35
PRODUC	R&D-1, NET-RIC	0,60
PRODUC	R&D-1, NET-OTH	-0,06
PRODUC	R&D-1, NET-CL	**1,48**
PRODUC	R&D-1,NETOUT	**1,39**
PRODUC	R&D-1, OUT	-0,22
PRODUC	NET, INNOORG	0,67
PRODUC	NET, ICT1	**1,63**
PRODUC	NET, ICT2	1,07
PRODUC	R&D, INNOORG	-1,13
PRODUC	R&D, ICT1	-0,90
PRODUC	R&D, ICT2	-0,73
PRODUC	R&D-1, INNOORG	-0,48
PRODUC	R&D-1, ICT1	-0,19
PRODUC	R&D-1, ICT2	-0,61
INNOTECH	R&D, NET	0,17
INNOTECH	R&D, NET-RIC	0,67
INNOTECH	R&D, NET-OTH	**-1,73**
INNOTECH	R&D, NET-CL	0,26
INNOTECH	R&D-NETOUT	0,44
INNOTECH	R&D, OUT	0,26
INNOTECH	R&D-1, NET	-0,36
INNOTECH	R&D-1, NET-RIC	-0,73
INNOTECH	R&D-1, NET-OTH	-1,17
INNOTECH	R&D-1, NET-CL	-0,71
INNOTECH	R&D-1, NETOUT	0,17
INNOTECH	R&D-1, OUT	0,06
INNOTECH	NET, INNOORG	0,28
INNOTECH	NET, ICT1	-0,52
INNOTECH	NET, ICT2	**1,52**
INNOTECH	R&D, INNOORG	-0,50
INNOTECH	R&D, ICT1	0,66
INNOTECH	R&D, ICT2	0,32
INNOTECH	R&D-1, INNOORG	**-1,37**
INNOTECH	R&D-1, ICT1	0,10
INNOTECH	R&D-1, ICT2	0,05
PROC	R&D, NET	**-1,73**
PROC	R&D, NET-RIC	-0,54
PROC	R&D, NET-OTH	**-2,25**
PROC	R&D, NET-CL	**-1,38**
PROC	R&D-NETOUT	**-1,97**
PROC	R&D, OUT	0,28
PROC	R&D-1, NET	**-1,74**
PROC	R&D-1, NET-RIC	-1,02
PROC	R&D-1, NET-OTH	**-1,93**
PROC	R&D-1, NET-CL	**-1,71**
PROC	R&D-1, NETOUT	**-1,34**
PROC	R&D-1, OUT	0,10
PROD	R&D, NET	0,15
PROD	R&D, NET-RIC	0,68
PROD	R&D, NET-OTH	0,61
PROD	R&D, NET-CL	0,41
PROD	R&D-NETOUT	**1,98**
PROD	R&D, OUT	0,40
PROD	R&D-1, NET	0,001
PROD	R&D-1, NET-RIC	-0,35
PROD	R&D-1, NET-OTH	0,90
PROD	R&D-1, NET-CL	-0,70
PROD	R&D-1, NETOUT	0,46
PROD	R&D-1, OUT	-0,96