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Abstract

This paper investigates the hypothesis that social capital is a crucial factor in explaining technological innovation in industrial districts or, more generally, in firms' clusters. Nevertheless, the fundamental idea is that social capital is not, as generally suggested by the socio-economic literature, an individual attitude towards 'something good', within a public good or collective good conceptual framework: the effect of SC in networks depends on its complementarity to private benefits and on the opportunity costs of purely private capital factors.

A dynamic theoretical model that assumes social capital as the public component of the impure public good R&D is developed. It shows that the 'civic culture' of the district area in which the firm works is not sufficient as an incentive to increase her investment in social capital, because this investment strictly depends on the economic convenience in investing in the impure public good. Social capital /networking dynamics might positively and complementary evolve only if the opportunity cost of investing in innovation is sufficiently low.

We consequently focus our attention on a specialized industrial district located in the Emilia Romagna region – the biomedical district of Mirandola (Modena) – characterised by a strong pattern of innovative activity. Using technological innovation as dependant variable, we observe that R&D and networking/social capital arise as complementary driving forces for innovation outputs. When empirical evidence confirms that this complementarity plays key role, and consequently strong links exist between market and non-market dynamics relating to firms, the role for policy actions targeted to social capital is wider. The policy effort should be targeted toward both market and non-market characteristics taken together, rather than solely to the production of (local) public goods (social capital) or innovation inputs as independent elements of firm's processes. Social capital alone is not a sufficient input for innovations and growth: economic incentives matter. On the other hand, whenever SC dynamics are crucial for R&D private investments, the effect of economic incentives depends on the presence and degree of their complementarity.

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1. Introduction

The fundamental idea behind this paper is that social capital (SC hereafter) is not, as generally suggested by the socio-economic literature, an individual attitude towards 'something good'. Actually, SC might and should be interpreted as a public component of an investment which implies private and public benefits entangled to each other.

In order to put forward this idea, a dynamic theoretical model is developed, that assumes SC as a public component of an impure public good: i.e. R&D. This theoretical model shows that, assuming complementarity between SC and R&D, the 'civic culture' of an industrial district is not sufficient as an incentive, to increase investments in SC by any single firm joining the district, because this investment also depends on the economic convenience in investing in the impure public good.

The subsequent empirical analysis allows us to assess the degree of such complementarity between SC and R&D, in a specific district-based industrialised context, using original survey data. In particular, we focus our attention on a Marshallian industrial district located in the Emilia Romagna region – the biomedical district of Mirandola (Modena) – which is characterised by a strong pattern of innovative activity. Using original survey data on firm's innovation practices, investment strategies, and cooperation efforts concerning firm's relationship and networking within and outside the district, a complementary positive effect between SC and R&D investments is detected estimating different econometric specifications of an innovation equation.

A main conclusion of the paper is that if and only if the economic conditions, which determine a favourable environment to the investment in the impure public good, improve, it is likely to observe an increase in investments in SC by firms. SC/networking dynamics might positively evolve only if the opportunity cost of investing in innovation is sufficiently low.

The paper is organized as follows. In section two, we critically describe some of the main results of the recent literature on SC. The most relevant definitions are presented and discussed. Hence a conceptual framework for SC is provided, essentially based on the concept of 'intensity of networking activities' concerning network-involved agents. The framework largely draws upon works of impure public good production and non-cooperative agreements. In section three, a theoretical model is presented, wherein the accumulation of SC is assumed as the public component of the impure public capital R&D, and the main implications of the model are discussed. In section four, we present our empirical exercise. Estimating an innovation equation, we detect a positive relationship between the intensity of SC (measured by a firm's specific index of cooperative intensity within the district) and the level of innovative actions observed. Moreover, R&D and SC/networking arises as complementary driving forces behind innovative activity. The last section concludes the paper.

2. Social capital: a framework for theoretical and empirical analysis

The main problem concerning the economic analysis of what has been termed 'SC' is that the literature is strongly heterogeneous, and the notion of SC is not always clearly assessed and described to be operative on theoretical and applied grounds. This is probably caused by the past emphasis on inter-disciplinary research, which has characterised the SC arena over the nineties, and was definitely necessary in the initial phase to generate a conceptual and theoretical debate. Some definitions are nevertheless too sociologically biased; others are still too vague. Our first goal was thus to extract from the literature the definitions we retain consistent, then present our own framework.

Among the various definitions we came across in the literature, the followings are the most relevant for defining the boundaries of the issue in question: (i) "A variety of different entities with two factors in common: they all consist of some aspects of social structure, and they facilitate certain actions – whether personal or corporate actors – within the structure" (Coleman, 1988); (ii) "Those features of social organization, such as trust, norms, and networks that can improve the efficiency of society by facilitating coordinate actions" (Putnam, 1993); (iii) "A glue that holds societies together" (Serageldin, 1996).

Taking into account the above definitions, SC is possibly identifiable with the 'culture' of a group of agents, a culture of economic reciprocity and cooperation. More generally, two key issues arise up from the socio-economic literature, those of 'trust' and 'ease of cooperation'.

Paldam (2000) specifically provides meanings revolving around the notion of trust, cooperation and network. The author correctly defines SC as the glue generating excess cooperation; we here add 'in excess' with respect to an equilibrium intended in a Cournot-Nash meaning. Trust and ease of cooperation are two factors that simultaneously interact in the production of private and public goods, or forms of capital.

We argue it is essential to move away from 'associative' based concepts of SC as presented in Robison *et al.* (2002) and Putnam (1993), and from analysis of trust and cooperation relying on 'honesty' treated as a sort of public good, toward frameworks where SC is conceived as an intangible capital stock with some public good-like properties worth investigating further.

Since the accumulation of SC in this realm is by definition self-monitoring, it can be considered a factor that affects, to some degree, the level of monitoring costs. The costs are reduced if the cooperative agreement reaches an equilibrium which self-sustains itself on a bundle of incentives (Paldam and Svendsen, 1999).

SC is then here studied as the public component of an impure public good[1], in which agents invest. Along this line of reasoning, SC emerges as a stock of accumulating capital deriving from a process of voluntary cooperation for the fulfilment of common objectives. We may say that the formation of SC lies in between the 'market' and 'hierarchy' structures. Investments are made with the sole support of market institutions (where agents voluntary participate in exchanges), nevertheless, investments are asset specific and the opportunity cost of non investing in SC is sunk, specific to the voluntary agreement under analysis.

Theoretically speaking, SC may be included in a production function together with other inputs, linked with them to different degree of complementarity. The effects of SC are therefore analysed according to the shape of cost functions, returns to scale, factor productivity, market and shadow prices of capital investments[2].

A contingent definition of SC emerges: SC is an intermediate capital good privately and intentionally produced, which endogenously accumulates from the flow of agents investments in voluntary cooperative effort. SC might be also conceived as the stock of the public component of an impure-public good, sustained by a set of private incentives. Its 'production' and accumulation are self-enforcing and sustained by reciprocal benefits of cooperation (Mancinelli and Mazzanti, 2004; Galassi and Mancinelli, 2004).

It is clear that the above definition hints at a microeconomic approach, differentiating the present analysis from that mostly found in the literature so far. It thus lies within the 'narrow'

[1] In the economic literature, an impure public good, or mixed-public good, is a good which jointly gives private and public benefits (Cornes and Sandler, 1986). 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. The definition of impure public good well applies "to an activity like philanthropy, where charitable activities provide private as well as public benefits to contributors" (Cornes and Sandler, 1984, p. 580). "The acquisition of certain types of education is often asserted to have benefits for society at large, in addition to purely private benefits generated for students. […] The acts of charity and of saving and the activities of military alliances are a few of the many instances that have been claimed as examples of the joint production of both a public and a private benefits." (Cornes and Sandler, 1986, p. 115).

[2] The SC investments may also be treated as shifting downward the cost function of the firm, as a type of collective external economies*,* involving both scope and scale economies (Oughton and Whittam, 1997). In this sense, SC as a stock captures the idea that collective external economies of scale are realised by cooperation over input activities, such as research, technological development, organisational innovation, training and advertising, wherein fixed costs are pooled among agents who join (Caloghirou *et al.*, 2003).

definition of SC, following the World Bank (1997) terminology for microeconomic approaches[3], in opposition to wider meso and macro approaches.

As far as the capital-like properties are concerned, SC as above defined owns a transformation capacity, in the sense that its accumulation is targeted toward the production of other forms of capital (man made or organizational) or final outputs[4]. It is durable as long as incentives exist to sustain it. In our case, the degree of durability is such that the stock elapses with the cooperative agreements established for specific objectives. Then, the breaking down of a coalition ends the value of the stock. Third, SC accumulates or de-cumulates depending on the structure of individual incentives (benefits and costs), and it is subject to decay as a renewable 'collective resource'. In fact, decay depends on endogenous factors such as easy riding (non consistent actions of investment between agents) and on exogenous factors; investment flows are thus necessary for maintaining the stock. Contrary to Sandler's analysis of intergenerational club goods (Sandler, 1982 and 1992), depreciation occurs because of a lack of strategic investment (reduced investment) in cooperation at any time *t*, rather than as a direct consequence of capital 'use' (crowding externality). In other words, depreciation derives from 'non use' rather than excessive use, as for many forms of collective manmade capital. Depreciation reflects the fact that much of SC investment is community-network specific.

The only capital-like property SC lacks is alienability, since we have shown that the stock of SC is intrinsically a relational dependent stock, consistently with Coleman's vision. It is not owned by individual agents or by the agents as a group, it is 'asset specific' and an instrument for the purposes of the alliance. Nevertheless, we argue the 'inalienability' is the main specificity of SC indented as an intangible real asset. Inalienability is linked to non-marketability, in that agents invest in some imperfectly observable assets: costliness and imperfect observability are the main factors responsible for the systemic easy riding with respect to investment decisions. Thus, is SC a real form of (intangible) capital with respect to our definition? We believe it is.

[3] Wherein SC is included and studied as the 'missing link', or residual and intangible capital factor, in explaining growth and development of economic systems. This is the 'orthodox' approach to SC within economics. SC is the fourth form of capital, after man made, natural and human capital, in other words the 'glue' that (i) may enhance other factor's productivity, (ii) reduces problems associated to 'common property resources' and (iii) generically helps development to occur on sustainable basis (Cote and Healy, 2001). For a heterodox view on SC see Fine (2001).

[4] The definition of SC as a stock of intangibles is not a completely shared vision. For instance, Arrow (1999) and Solow (1999) sharply conclude that the emphasis on capital is probably misplaced. SC derives instead from an association to the concept of human capital. In their view, the fact that factors such as trust, cooperativeness, and propensity to invest in a common effort have on the one hand a clear cut effect on total productivity, but on the other hand economics cannot consistently deal with SC as a proper form of capital. Other authors (Stiglitz, 1999) are more in favour of the SC consistency within economics.

The framework highlights that what really matters is that agents at some point need to join their efforts for achieving benefits which derive from and build on public-like forms of investments. The most common and relevant benefit deriving from firm cooperation is that associated to the development of technological (process and product-based) innovations. This necessary joint effort in establishing 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 SC 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. The community benefits from positive network externalities. Nevertheless, differently from pure exogenous spillovers, the voluntary and intentional production of joint social benefits is costly: therefore incentives matter.

The public element of welfare function of one firm participating to the network agreement is, in our framework, the stock of SC on which the decision of action relies. SC is nevertheless strictly connected to private components of welfare (it is not a pure 'independent' public good), to which is linked by some degree of complementarity relationship. We may intend the investment on the impure public good as a network-specific R&D investment, generating product and process innovations. SC and R&D may be hypothesised as two jointly associated driving forces of innovation activities in local industrial realms, where economies of scale may in part be exploited by investments in networking and R&D cooperation, to produce local impure public good[5].

As far as the measurement of SC is concerned, the main ways of approaching SC quantification at microeconomic level[6] are three: by using (i) regional/national official dataset;

[5] It is worth underlining the voluntary element of the agreements in cooperation and production: SC is self-enforcing, self-financing, in opposition to third-party enforcement frameworks. Thus, we may say that our SC environment belongs to a Coasian-like framework characterised by horizontal relationships, in opposition to third-party enforcement pigouvian-like institutional frameworks.

[6] We do not follow the macro-economic direction, which has dominated until recently the empirical measurement of SC, for two reasons. First, the conceptual focus is here strictly microeconomic. Secondly, the weaknesses of that

(ii) revealed preference approaches (observing agent's behaviour), which includes both quantifying by observing choices (i.e. investment choices, participation rates, etc.); (iii) stated preferences methods (directly revealing behaviour when observation is difficult or we lack behavioural 'tracks'), which include quantifying SC by direct methods (i.e. interviewing economic agents).

The main obstacle in using the first method, generally less costly, is that SC features are usually non-market and non-accounted in regional and national dataset[7]. Thus, the only consistent way to elicit the SC private and public characteristics is often by implementing survey-based approaches aimed at eliciting specific information by structured questionnaires. The questionnaire should attempt to gather information consistent with conceptual definitions, by recovering data on SC factors, R&D dynamics and other firm-specific factors possibly affecting innovation, which we may use as controls.

Next sections present (i) the theoretical model, which further defines the conceptual environment of the work, then (ii) the empirical investigation of the relationship between R&D and SC and their role in fostering innovation. The study grounds on original information elicited from firms belonging to an industrial district where innovation is the predominant factor for boosting growth and economic performance in the local environment. Though our case study allows a limited level of generalisation, we believe this is the proper direction for investigating SC dynamics in an integrated theoretical and applied approach.

3. The model

From the framework of SC designed in the previous section, SC clearly emerges not as an individual attitude towards 'something good', or a simple pure public good, but instead, as the public component of an investment which implies a share of privately appropriable benefits[8].

For instance, the environment faced by firms located within an industrial district may be depicted as follows: on the one hand, a firm has the option of investing either in standard technology or in incremental innovations which do not require cooperative efforts (the firm internalises investments and associated returns). Both options may be termed as 'Business as

research direction (specifically the weak conceptual framework for SC) have recently been extensively highlighted by various authors, who claim the greater added value of a microeconomic applied research direction (Sobel, 2002; Durlauf, 2004; 2002).

[7] For this reason, most studies on SC using official data adopt SC proxies, which lack robustness in terms of conceptual and /or theoretical foundations. See, among the others, Guiso, Sapienza and Zingales (2000) who introduce some ad hoc SC proxies as determinants of financial development.

Usual' (BAU) scenarios. On the other hand, the firm may invest in R&D which implies innovations that involve structural breaks from the BAU (discrete changes concerning technological/organisational development) and that involve skills, knowledge and competences, which the firm only partially owns. In this case, the innovation change usually requires a cooperative effort, and the investment may be thought as one in an impure public good, that is each unit of investment produces some percentage units of private benefits and some percentage units of public benefits. Private benefits are, for instance, technological amelioration appropriable by the firm and public benefits derive from the cooperative agreements among firms (Mazzanti and Zoboli, 2004).

The aim of this section is to analyse the accumulation of SC by district firms, through the development of a dynamic theoretical model where SC is assumed to be the public component of an impure public good – the R&D investment – following the example depicted above.

The analysis builds up and brings together, attempting to shape an original model the treatment of SC, the contributions given by Cornes and Sandler (1984 and 1986) and Glaeser *et al.* (2002).

3.1 Firms belonging to an industrial district

We assume that there exists an industrial district composed of N firms[9]. Each firm invests in two kinds of capital, y_i and R_i. y_i has mere private characteristics and R_i has the characteristics of an impure public good. It has (produces) either a private characteristic, z_i (which has no effects on the other firms) and a public characteristic, s_i (which has effects also on the other districts firms).

The investment in the private kind of capital, y_i, can represent an investment in a BAU ('business as usual') capital stock, and the investment in the 'impure public' capital[10], R_i, can represent an investment in R&D. In this case we can take as example of the private component, z_i, the technological amelioration appropriable by the firm, and as example of the 'public component', s_i, the formation of voluntary and self enforcing agreements among firms.

Therefore, the public component, s_i, is consistent with the definition of SC presented in section two. Actually, s_i is an intermediate capital good privately and intentionally produced,

[8] The idea that investment in SC is linked to economic factors, which imply private benefits, has already been investigated in other works (Galassi, 2001).

[9] Each firm is indexed by the subscript $i=1,\dots, N$.

[10] Notice that we do not deal with club goods because here the size of the community (network) consuming the public good is exogenously fixed. This characteristic (community size) does not appear explicitly in the analysis.

which endogenously accumulates from the flow of agents investments in voluntary cooperative effort; and it is also the public component of an impure-public good.

Since R_i has the characteristic of an impure public good, each unit of investment by the firm *i* in R_i is such that:

(1) $$z_i = \alpha_i R_i \qquad 0 \leq \alpha_i \leq 1 \textit{ given}$$

(2) $$s_i = \beta_i R_i \qquad 0 < \beta_i \leq 1 \textit{ given}$$

Where α_i and β_i are exogenously given coefficients reflecting a simple process, whereby z_i and s_i are jointly generated in fixed proportion by the investment in R_i.

We are hence assuming that whenever a firm invests in one unit of R_i, she invests in $1/\alpha_i$ given units of a private characteristic and in $1/\beta_I$ given units of SC[11]. That is whenever a firm invests in one unit of R_i, her investment is in some percentage an investment in a private asset and in some percentage an investment in SC.

Moreover, since s_i exerts effects also on the other firms inside the industrial district and *vice versa*, we define:

(3) $$S_{\neq i} = \sum_{j \neq i} s_j = \sum_{j \neq i} \beta_j R_j \qquad \forall\ i, j$$

and:

(4) $$S = \sum_{i=1}^{N} s_i = \sum_{i=1}^{N} \beta_i R_i = s_i + S_{\neq i}$$

The whole quantity of the public characteristic (S) is given by the sum of the single contributions by any firm.

We adopt the Nash-Cournot assumption that the single firm *i* regards $S_{\neq i}$ as exogenously given.

From equations (1), (2), (3) and (4) the investment of firm *i* in one unit of R_i has therefore three effects: (i) an increase in *i*'s private benefits due to the private characteristic, z_i ($=\alpha_i R_i$); (ii) an increase in the total amount of the public component available to any firm inside the network ($S = s_i + S_{\neq i}$); (iii) an increase in *i*'s private benefits due to the public characteristic ($s_i + S_{\neq i}$).

Hence, we can define firm *i*'s benefit function of the investment in the impure public capital, R_i as:

(5) $$B_i = B_i\left[\left(S_{\neq i} + s_i\right), z_i, I_{R_i}\right] \qquad \forall i$$

and, from equations (1) and (2) it can be written as:

(6) $$B_i = B_i\left[\left(\beta_i R_i + S_{\neq i}\right), \alpha_i R_i, I_{R_i}\right] \qquad \forall i$$

Since, from equation (6) firm *i*'s benefit function depends on the firm *i*'s choice about the investment R_i-related flow variable (I_{R_i}), on the consequent choice on the stock variable (R_i) and on the other firms choice about $S_{\neq i}$, it can also be expressed as follows:

(7) $$B_i\left[\left(S_{\neq i} + s_i\right), z_i, I_{R_i}\right] = B_i\left[\left(\beta_i R_i + S_{\neq i}\right), \alpha_i R_i, I_{R_i}\right]$$
$$= V_i\left[, R_i, I_{R_i}, S_{\neq i}\right] \qquad \forall i$$

We assume that firm *i*'s benefit function is continuous, strictly increasing, strictly quasi-concave, and everywhere twice differentiable with respect to all its arguments.

We can define the investment cost function of any firm *i* regarding the impure public capital R_i as:

(8) $$C_i = C_i(I_{R_i}) \qquad \forall i$$

with $C_i^{'}(.) \geq 0$, and $C_i^{''}(.) \geq 0$.

Since the variation of R_i stock in time is:

(9) $$\frac{\partial R_i}{\partial t} = \dot{R}_i = I_{R_i} - \delta R_i \qquad \forall i$$

where δ is the exogenous depreciation factor, we can write the firm's investment cost function in R_i as:

(10) $$C_i = C_i(\dot{R}_i + \delta R_i) \qquad \forall i$$

[11] Notice that, by equation (2) we assume that s_i can never be zero, because we suppose that each firm inside the district invests at least a minimum positive amount in "networking" and establishes even the simplest form of relationships or agreement.

Moreover we assume that firms are symmetric: they have identical investment cost functions, and we assume that the opportunity cost of the impure public capital R_i is r (that is the value of the private capital, y_i).

From equations (7), (9) and (10), the problem of each district firm can be expressed as the typical problem of the determination of the optimal control path ($I^*_{R_i}(t)$) and of the optimal state path ($R_i^*(t)$).

Since we have assumed that R_i is an impure public capital, that is it jointly produces a private characteristic, z_i, and a public characteristic, s_i, we can assert, following Cornes and Sandler (1984 and 1986), that the two characteristics, z_i and s_i, are complements. That is increasing one of them increases the benefits of increasing the other (Milgrom and Roberts, 1995). In terms of mixed-partial derivatives of firm *i*'s benefit function, complementarity between z_i and s_i can be expressed as:

$$(11) \qquad \frac{\partial^2 B_i}{\partial z_i \partial s_i} \geq 0.$$

3.2 The accumulation of social capital inside an industrial district

We assume that each firm inside the industrial district has a known lifespan of T periods and that she discounts the future with the discount factor ρ.

Each firm wants to maximise her net benefit function[12], in the interval of time $[0, T]$:

$$\textit{Maximize} \int_0^T \left\{ V_i\left[, R_i, I_{R_i}, S_{\neq i}\right] - rC_i\left(I_{R_i}\right)\right\} e^{-\rho t} dt$$

s.t:

$$\dot{R}_i = I_{R_i} - \delta R_i .$$

Where the transversality conditions are: $R_i(0) = \bar{R}_i$, $R_i(T)$ free ($\bar{R}_i$, T given), and $\lambda(T)=0$.

From equation (2) and (7) firm *i*'s problem may be expressed also as:

$$\textit{Maximize} \int_0^T \left\{ B_i\left[\left(s_i + S_{\neq i}\right), \alpha_i R_i, I_{R_i}\right] - rC_i\left(I_{R_i}\right)\right\} e^{-\rho t} dt$$

s.t.:

$$\dot{R}_i = I_{R_i} - \delta R_i .$$

[12] For each firm, R_i is the state variable and I_{Ri} is the control variable.

The Hamiltonian is:

$$H(t, R_i, I_{R_i}, \lambda) = \{B_i[(s_i + S_{\neq i}), \alpha_i R_i, I_{R_i}] - rC_i(I_{R_i})\}e^{-\rho t} + \lambda(t)(I_{R_i} - \delta R_i)$$

From the second maximum principle condition (equation of motion for λ, $\dot{\lambda} = -\frac{\partial H}{\partial R_i}$), we get[13]:

$$(12)\ \lambda^*(t) = \frac{\left[\frac{\partial B_i(.)}{\partial(s_i + S_{\neq i})}\beta_i + \frac{\partial B_i(.)}{\partial R_i}\alpha_i\right]}{(\rho+\delta)}(e^{-\rho t} - e^{-(\rho+\delta)T+\delta t}).$$

Substituting in the first maximum principle condition ($\frac{\partial H}{\partial I_{R_i}}$), we have:

$$(13)\quad \frac{\partial H}{\partial I_{R_i}} : e^{-\rho t}\left[\frac{\partial B_i(.)}{\partial I_{R_i}} - r\frac{\partial C_i(.)}{\partial I_{R_i}}\right] + \frac{\left[\frac{\partial B_i(.)}{\partial(s_i + S_{\neq i})}\beta_i + \frac{\partial B_i(.)}{\partial R_i}\alpha_i\right]}{(\rho+\delta)}(e^{-\rho t} - e^{-(\rho+\delta)T+\delta t}) = 0$$

Equation (13) represents, the optimal control path ($I^*_{R_i}(t)$).

Differentiating (13) with respect to *r* we get:

$$(14)\ \frac{\partial^2 H}{\partial I_{R_i}\partial r} : -e^{-\rho t}\frac{\partial C_i(.)}{\partial I_{R_i}} < 0$$

That is, in each period *t* firm *i*'s optimal level of investment in R_i decreases at the increasing of the opportunity cost of R_i.

Moreover, if we totally differentiate equation (13) with respect to s_i and $S_{\neq I}$, we get[14]:

$$(15)\ \frac{ds_i}{dS_{\neq i}} = -\frac{\beta_i B_{i_{S_{S\neq i}}}}{\left[\beta_i B_{i_{S_{s_i}}} + \alpha_i B_{i_{R_{s_i}}}\right]}$$

The sign of the numerator of eq. (15) depends on the sign of $\beta_i B_{i_{S_{S\neq i}}} = \beta_i \frac{\partial^2 B_i[(s_i + S_{\neq i}), \alpha_i R_i, I_{R_i}]}{\partial(s_i + S_{\neq i})^2}$, which is certainly non-positive, since we have assumed the strictly quasi-concavity of firm *i*'s benefit function.

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[13] The analytical steps to get equation (12) are shown in Appendix 1.

[14] Remind that: $s_i = \beta_i R_i$ and $S = s_i + S_{\neq i}$.

The sign of the term that appears in the square bracket at the denominator in equation (15) depends on the sign of $(\beta_i B_{i_{S_{S_i}}} + \alpha_i B_{i_{R_{S_i}}})$. Whereas $\beta_i B_{i_{S_{S_i}}} = \beta_i \frac{\partial^2 B_i\left[(s_i + S_{\neq i}), \alpha_i R_i, I_{R_i}\right]}{\partial (s_i + S_{\neq i})^2}$ is certainly non-positive, $B_{i_{R_{S_i}}}$ is nonnegative, since we have assumed that z_i and s_i are complementary, hence $\frac{\partial^2 B_i}{\partial \alpha_i R_i \partial s_i} \geq 0$. Since the technological parameters, α_i and β_i, are independently determined, one cannot rule out the possibility that $\left|\alpha_i B_{i_{R_{S_i}}}\right| > \left|\beta_i B_{i_{S_{S_i}}}\right|$. In this way, complementarity between z_i and s_i can produce, in each period t, a positive response:

$$(16) \qquad \frac{ds_i}{dS_{\neq i}} > 0$$

Hence, in the case depicted above ($ds_i / dS_{\neq i} > 0$), the reaction curve may have positive slope: in this case, an increase in $S_{\neq i}$ raises firm *i*'s benefits due to the public characteristic (s_i+$S_{\neq i}$), which, in turn, rises the single firm's marginal valuation for the complementary private characteristic z_i. As a consequence, the single firm now wishes to increase her investment in R_i. To do this, the single firm must increase her stock of R_i, which has the effect of increasing s_i (via $s_i = \beta_i R_i$), her own generation of the public characteristic (SC).

The conclusion is that if the other firms' investment in SC ($S_{\neq i}$) increases, also the single firm *i*'s investment in SC may increase. Hence a positive 'culture' in an industrial district may have positive effects on the investment of SC by the single firm.

But the increases of the investment in s_i pass through firm *i*'s investment in R_i.

And from equation (14) we know that in each period *t* firm *i*'s optimal level of investment in R_i decreases at the increasing of the opportunity cost of R_i.

Hence, whenever the opportunity cost of R_i increases, the single firm *i* reduces her investment in R_i and, as a consequence, she reduces her investment in SC.

From the third maximum principle conditions (equation of motion for R_i, $\dot{R}_i = \partial H / \partial \lambda$) we get[15] the optimal state path:

$$(17) \qquad R_i^*(t) = \left(\bar{R}_i - \frac{I_{R_i}}{\delta}\right) e^{-\delta t} + \frac{I_{R_i}}{\delta}$$

[15] The analytical steps to get equation (17) are shown in Appendix 2.

Substituting with $I^*_{R_i}$:

$$(18) \qquad R_i^*(t) = \bar{R}_i\, e^{-\delta t} + \frac{I^*_{R_i}}{\delta}(1 - e^{-\delta t})$$

From the results of the model we can deduce that if SC is the public component of an impure public capital, an increase of the other firms' investment in the public component (SC) may induce firm i to increase her own investment of the impure public capital R_i, and, as a consequence, to increase her own investment of SC (s_i). If we consider high levels of investments in SC by the district firms as strictly associated to the level of 'civic culture' of that district, the result of the model confirms what part of the literature on SC[16] asserts. That is, the level of investment in SC by an individual economic agent is positively related to the civic culture of the geographic area in which the economic agent acts.

Nevertheless, as shown above, this virtuous circle happens only when the opportunity cost of the impure public capital is sufficiently low: if the opportunity cost of R_i is too high, the single firm will not increase her investment in R_i, and as a consequence, will not increase her investment in SC, even if the availability of SC provided by the other firms is high.

Hence, if SC is definable as the public component of an impure public capital, the 'civic culture' of the district area to which the firm belongs is not sufficient to increase her investment in SC, because this investment depends also on the economic profitability in investing in the impure public capital. This is true for each firm inside the industrial district. Therefore, the whole level of investment in SC inside the district tend to be correlated to the costs of the economic actions. In the case depicted above, the higher the opportunity costs of R&D (conversely, the lower the profitability of innovation), the lower the stock level of SC.

As a conclusion, if and only if the economic conditions, which determine a favourable environment to the investment in the impure public capital, improve, it is possible to hope in an increase of the investments in SC by economic agents. If SC is assessed as the public component of an impure public good which is a crucial intermediate capital good for firm

[16] We refer to that line of analysis which mainly stems from the famous contributions associated to the work of Fukuyama (1995) and Putnam (1993). The latter is indeed famous for a study on SC taking Italy as case study. The interest of both approaches is on 'culture' and 'institutions', but no attempt is made to analysing what the causes of SC formation and development are. The interest is here on effects and on comparative analyses between areas and regions. The main risk of this approach is to explain social phenomenon only by the (observed) status quo culture, with minor attention to economic and political dynamic elements. What often emerges from this approach to SC is that geographic areas in which investments in SC are low are typically characterised by a low level of 'civic culture'. The reasons for which this happens are not explored and, as a consequence, the economic incentives behind the investments in SC are not investigated.

performance and innovation practices, the incentive devices to invest in SC are also economic-biased, and they are not only linked to the 'civic culture' of the geographic area.

It is worth emphasizing how crucial it is, for the implications of our theoretical model, assuming that SC is the public component of the impure public capital R&D.

The aim of the following empirical analysis is to test the assumption of complementarity between SC and R&D in a specific Italian industrial district: the biomedical district of Mirandola (Modena).

4. SC and R&D investments as complements: an empirical test

4.1 The data-set

The framework depicted above characterises different real-world situations where inter-firm cooperation is the primary and leading key to successful performance of industrial districts. Along this line, networking is a capital good and an intermediate input to production. Although we underline that the present analysis is highly specific concerning the elicited data, recent works taking a similar perspective are, among the others, Cassiman and Veugelers (2002), Becker and Dietz (2004), Fritsch and Franke (2004), Negassi (2004). Those papers deal with innovation activities, R&D cooperation and (knowledge) spillovers, taking different perspectives and research directions. Summing up, they attempt to identify what the determinants of R&D intensity; R&D cooperation and innovation activities are specifying diverse reduced forms[17]. Building up on that research line, we here attempt to focus attention on the nexus of complementarity between networking and R&D as joint inputs for technological innovation.

Now let us show how we set up the case study analysis for the biomedical industrial district of Mirandola (Modena). The empirical identification of the manufacturing firms belonging to this industrial district is carried out taking into account two different dimensions: (i) productive specialization and (ii) geographic area in which firms are located. Concerning productive specialization, we included in the sample all the manufacturing firms belonging to the ATECO classes 33.10[18]: *Manufacture of medical and surgical equipment and orthopaedic appliances*. Concerning the localization area of the district, we took into consideration the following seven municipalities of

[17] Becker and Dietz (2004) estimate reduced forms for input and output innovation measures regressed over R&D cooperation and networking proxies. Fritsch and Franke (2004) use patent datasets to estimate the effect of both R&D intensity and R&D regional spillovers. Cassiman and Veugelers (2002) try instead to use R&D cooperation as dependant variable, explained by spillovers measures. Negassi (2004) exploits information concerning the budget spent on R&D cooperation and turnover based innovation measures.

the *Provincia* of Modena[19]: Mirandola, Medolla, Concordia, Cavezzo, San Felice sul Panaro, San Possidonio and San Prospero. The reason behind this choice is that these municipalities are associated to higher concentrations of biomedical firms. We thus identified the 'biomedical district of Mirandola' by taking into account only those firms satisfying two requirements: (i) operating in the sector 33.10 *Manufacture of medical and surgical equipment and orthopaedic appliances* and (ii) headquarters are located in one of the seven municipalities already listed.

We then identified a universe population of district firms that has been identified during an extensive research project realised years ago on this district (Baracchi and Bigarelli, 2001)[20]. We directly interviewed firm managers during a two-months period (February-March 2004) by administering a short but focussed and structured questionnaire, in order to elicit data on innovation practices, R&D investment, and cooperation efforts concerning firm's relationship and networking within and outside the local district. The selected period of reference is 2000-2002. As far as R&D data are concerned, it was reasonably possible to ask firms annual data for each year from 2000 to 2002, while all questions regarding networking activities and innovation practices ask to determine a 'trend' over the 2000-2002 period[21]. We decided not to elicit information on performance to minimise the rejection rate; in addition, survey data on performances are known to be often lacking reliability. The first part of the questionnaire deals with general features of firms, the second part focuses on innovation practices, the third part on networking activities. The final dataset accounts for 40 of the 70 firms setting up the district 'population'. Few firms refused to join, most of data losses derived from firm shutdowns, especially for smaller establishments. As it turns out from Tables A.1, A.2, and A.3 in Appendix 3, the coverage rate of our dataset appears to be quite good. This is true both when considering all the firms (Table A.1), firms producing for final markets (Table A.2), and sub-contractors (Table A.3).

[18] Economic activity classes defined by the Italian National Statistical Institute (ISTAT).

[19] Modena is a central Province of the Emilia-Romagna Region. Emilia Romagna is an area of Italy characterised by a high density of industrial districts, a GDP per capita (about 27000€ in 2003) higher than the Italian average and with four millions residents represents the 7% of the Italian population.

[20] We argue that the main added value of current empirical analysis on SC may derive from focused survey study eliciting specific and often 'latent' information which are not accounted for in market transaction and official data (i.e. Community Innovation Survey, national or regional statistics). With this respect, our analysis differs from studies using large, public but not focussed dataset (Cassiman and Veugelers, 2003).

[21] This is a key problem for empirical analysis concerning innovation and SC dynamics, since such data are difficulty, if not impossibly, revealed on an annual basis by firms.

4.2 The empirical analysis

This section illustrates the econometric methodology used to empirically test the aforementioned complementarity between R&D and SC/networking. In order to perform this exercise, we estimate an innovation equation, which expresses the relationship between innovation output and innovation inputs within a 'conceptual framework' of a knowledge production function (Griliches, 1979; Fritsch and Franke, 2004). The estimable reduced form we use as it follows:

$$\text{(19)} \qquad \begin{array}{lll} \mathrm{INN}_{\mathrm{i,t}} = 1 & \text{if} & \mathrm{INN}_{\mathrm{i,t}}^{*} = \alpha_0 + \alpha_1 \cdot RD_{i,t-1} + \alpha_2 \cdot NET_{i,t} + \mathbf{X}_{i,t-1}\beta_1 + u_i \\ \mathrm{INN}_{1,\mathrm{t}} = 0 & \text{otherwise} & \end{array}$$

A brief description is necessary. $INN_{i,t}$ is a binary variable taking the value of 1 whether the firm *i* introduced product and/or process technological innovations over the 2000-2002 period[22]. RD_i is the Research and Development expenditure per employee of firm *i*.

In order to cope with endogeneity and introducing a lagged effect, we decided to use the 2000 value as independent variable proxy for R&D. NET_i is a variable capturing the networking effects concerning the SC oriented activity of firm *i*, which was addressed by a specific and focussed part of the questionnaire. More specifically, two different dummies are introduced as proxies for SC. The first takes the value of one when a firm is associated to formal or informal networking relationships, dealing with production issues, innovation issues and market strategies. The second dummy takes the value one if a firm exploits other firms belonging to the same district (exchanging flows of critical information)[23] as a main source of information. The vector $\mathbf{X_i}$ includes a set of control variables (firm's typology, size, age, and export propensity) which we included to better specify the vector of innovation inputs. Otherwise, the effect of R&D and networking could be overestimated. Finally, u_i denotes the error term with the standard statistical properties. It is worth noting that all the explanatory variables are expressed in natural logarithms.

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[22] See Negassi (2004), among others, for a critical debate over the various innovation proxy measures, on the input and output side.

[23] See Cassiman and Veugelers (2002) for a discussion on the role of incoming (information) spillovers as an engine for R&D cooperation and, indirectly, for innovation.

Before showing and commenting the findings of the econometric investigation, we first present some results of the field survey (Tables 1 and 2) and then some descriptive statistics concerning the variables used (Table 3).

Table 1 – Firm size and R&D

Size classes	*Firms*	*Firms*	*Employees*	*Employees*	*R&D per employee*
	N.	%	N.	%	€
0-19	21	52.5	190	7.5	1,323
20-49	10	25.0	257	10.1	530
50-249	6	15.0	659	26.1	2,138
>249	3	7.5	1,424	56.3	6,017
Total	40	100.0	2,530	100.0	4,097

Table 2 – Innovations and networking

Size classes	*Final firms*	*Product innovations*	*Process innovations*	*Innovations*	*Networking*[(a)]	*Networking*[(b)]
	%	%	%	%	%	%
0-19	90.9	38.0	38.0	57.1	85.7	28.6
20-49	50.0	20.0	20.0	30.0	30.0	10.0
50-249	100.0	83.3	83.3	83.3	100.0	0.0
>249	100.0	100.0	100.0	100.0	66.6	33.3
Total	60.0	45.0	45.0	60.0	72.5	20.0

(a) This dummy takes value 1 if the firm is characterised by formal or informal networking relationships dealing with both production issues, innovation issues and market strategies.
(b) This dummy takes value 1 if the firm exploits and receives critical information from agents belonging to the same district.

From the analysis of Tables 1 and 2 emerges (i) that the percentage of innovative firms in this industrial district is quite high and, (ii) that this tendency tends to increase according with the firms' size. As far as the first networking variable is taken into account, one can note that also in this case the percentage of district firms involved is quite high. The second networking variable instead does not show the same pattern. In fact, this latter networking factor, with the exception of small-sized firms, seems to be less widespread.

The R&D per employee is increasing by size, confirming the expected positive correlation between the two variables. As a term of comparison, the italian industrial R&D value (year 2000) elicited by the Third Community Innovation Survey is about 3000€ considering only formalised R&D, and more than 8000€ including also expenditures on innovative man-made capitals, skilled labour training and know-how acquisitions.

Table 3 – Descriptive statistics (explanatory variables)

	N. OBS.	MEAN	STD. DEV.	MIN.	MAX.
Log(employees)	40	2.996	1.435	0	6.526
Firm Typology (a)	40	0.6	0.496	0	1
Firm Age (years)	40	13.8	8.811	2	34
Log(export/total turnover) in 2000	40	1.586	1.872	0	4.499
Dummy networking (b)	40	0.725	0.452	0	1
Dummy networking (c)	40	0.2	0.405	0	1
Log(R&D expenditure/employees in 2000)	40	3.193	3.880	0	10.183

(a) This dummy takes value 1 if the firm sells its products on the final market, 0 if the firm is primarily a sub-contractor.
(b) This dummy takes value 1 if the firm is characterised by formal or informal networking relationships dealing with both production issues, innovation issues and market strategies.
(c) This dummy takes value 1 if the firm exploits and receives critical information from agents belonging to the same district.

From the econometric point of view, the estimation of equation (19) poses at least two problems. First, heteroskedasticity, as it is often found when cross sectional data are used, may reduce the efficiency of econometric estimates. Thus, all estimates are carried out adopting a 'robust' estimator for the Logit model which addresses such source of bias. Secondly, there is a potential endogeneity of R&D in the regression. In fact, as many contributions have shown a lag between R&D input and innovation output is a general plausible assumption often verified by empirical assessment. We thus use the R&D data for 2000 as an explanatory factor for innovation over 2000-2002, introducing a 'lagged' term into the regression (thus specifying an hybrid cross sectional model)[24].

Let us now go back to the econometric findings. In Table 4, we report results for various specifications of equation (19). In particular, column [1] reports the reduced form when only control variables are included. In this case, all these explanatory variables result to be non-significant.

Focussing on the extended specifications [2-6] we note that the impact of R&D and networking as inputs of innovation is highly significant. It is worth highlighting two points. First, both the networking dummy variables are statistically significant when included separately as added covariate to the control variables of (19) (columns [2] and [5]). Secondly, the two "inputs" for which we hypotheses a complementarity nexus emerge statistically significant, when both are included (column [4] and [6]). This is an assessment of the joint/complementary driving stimulus provided by R&D and SC. Regressions [4] and [6] also shows the two highest pseudo-R^2.

[24] See Huselid and Becker (1996) and Cassiman and Veugelers (2002) for more insights on the issue.

Specifications [5-6] also show a significant effect of size, which nevertheless does not arise across estimates a primary force behind innovation.

We may conclude this section summarising the outcome of the econometric exercise. SC investments, proxied by two variables concerning networking activities, emerge a crucial driving force for innovation. Innovation is also triggered by expenditures in R&D, confirming what expected *ex ante*. Further, and definitely more important, SC/networking and R&D arise jointly determining technological innovation. The outcome is robustly confirmed by different econometric specifications of an innovation equation. Those aforementioned driving forces appear to overwhelm the effect of other explanatory factors of innovation, like firm size, which is usually found as a key driving force of innovation and high-performance practices. Only when considering the second networking variable, the variable capturing the market orientation of firms (value one if firms sell the product on the final market) and that capturing the firms' size results to be statistically significant in the regressions. This finding, although circumscribed to the district observed, is in contrast to the predominant size effects often emerging from studies on innovation practices, and with other evidence, which also tends to reduce the emphasis on R&D cooperation with respect to size, market share ad other firm-specific characteristics (Negassi, 2004). Further empirical evidence is thus necessary for a generalisation.

Table 4 – The innovation equation: estimates

	Dependent variable: *innovation dummy (2000-2002)*					
	[1]	[2]	[3]	[4]	[5]	[6]
Estimation Method	Logit(1)	Logit(1)	Logit(1)	Logit(1)	Logit(1)	Logit(1)
Constant	-0.400 [1.303]	-3.090 [2.190]	-0.094 [1.599]	-2.934 [2.242]	-1.483 [1.920]	-1.673 [1.883]
Log (employees)	0.292 [0.337]	0.657* [0.400]	0.175 [0.313]	0.488 [0.325]	0.687** [0.342]	0.645** [0.285]
Typology (c)	2.113 [1.102]	2.082 [1.706]	0.816 [1.215]	0.459 [1.688]	3.292** [1.171]	1.627 [1.083]
Log (Age)	-0.503 [0.586]	-0.297 0.669	-0.613 [0.778]	-0.343 [0.825]	-0.985 [0.752]	-1.061 [1.031]
Log(export/total turnover) in 2000	-0.024 [0.310]	-0.311 0.606	0.163 [0.385]	-0.022 [0.605]	-0.170 [0.327]	0.186 [0.471]
Dummy networking (a)	…	2.350** [1.162]	…	2.470** [1.063]	…	…
Dummy networking (b)	….	…	…	…	3.776** [1.758]	4.168** [1.859]
Log (R&D expenditure/employee) in 2000	…	…	0.303** [0.136]	0.319** [0.157]	…	0.354** [0.173]
N. Obs.	40	40	40	40	40	40
Pseudo-R^2	0.196	0.299	0.293	0.388	0.363	0.469

** significant at 5%; * significant at 10%

(1) Standard errors [in brackets] are computed with the White method in order to correct for heteroschedasticity.

(a) This dummy takes value 1 if the firm is characterised by formal or informal networking relationships dealing with th production issues, innovation issues and market strategies.

(b) This dummy takes value 1 if the firm exploits and receives critical information from agents belonging to the same district.

(c) This dummy takes value 1 if the firm sells its products on the final market, 0 if the firm is primarily a sub-contractor.

5. Conclusions

Building on the literature on SC mainly developed during the last decade, the main aim of this paper was to explore new perspectives, rooting on a microeconomic approach. The analysis conducted, both theoretical and empirical, helps shedding light on the ongoing SC debate, since it investigates the effective role of this capital input in stimulating innovative activity and thus economic performance.

Introducing a nexus of complementarity between R&D and SC, a dynamic theoretical model then has shown that if SC is the public component of the impure public good R&D in a district of firms, the 'civic culture' of the district area where the firm acts is not a sufficient explanatory factor to increase the firm investment in social capital, since this investment strictly depends also on the economic profitability (private opportunity costs) linked to innovative strategies involving firm cooperation. In other words, only if the economic conditions, which determine a favourable environment to the investment in the "impure public capital", improve, it is possible to hope in an increase of investments in SC by economic agents.

Empirical results confirm the nexus of complementarity between R&D and SC/networking activities, and help shedding light on the ongoing SC debate, in assessing the effective role of this capital input in stimulating innovation and, consequently, economic growth. We focused our attention on a biomedical industrial district. Econometric analysis shows that R&D and SC/networking consistently arise as complementary inputs for innovation outputs.

It is worth noting that the main outcome arising from the theoretical and empirical analysis – the pivotal role of complementarity associated between R&D and SC/networking on the input side of the production-innovation process – influences the perspective concerning policy action. Whenever empirical evidence highlights this keystone complementarity (though further evidence is needed to generalise the result), consequently, strong links exist between market and non-market dynamics relating to firms, and the role for policy actions targeted to SC should be larger in spirit. The policy effort should be targeted toward both market and non market (i.e. R&D and SC) characteristics taken together, rather than an effort directed to the production of (local) public goods (SC) or innovation inputs as independent elements of firm's specific processes. The difference is not purely speculative, but it matters as far as policy effectiveness is concerned. In fact, we argue that in the one hand SC/networking dynamics might positively evolve only if the private opportunity cost of investing in non-BAU innovation is sufficiently low. Nevertheless, this (exogenous) economic incentive works as long as complementarity, as here defined, holds. Otherwise, opportunistic behavior concerning cooperation for networking activities may undermine the development of R&D and innovation, even when economic conditions are favourably evolving (i.e. decreasing opportunity costs). Moreover, in the other hand, SC/networking is not a sufficient driver, as some authors have suggested, for generating innovative behavior and better economic performances, in absence of favourable economic incentives. This perspective leads to new research lines, given the necessity of investigating what the opportunity cost threshold may be in a specific environment.

The results of the theoretical model may deserve further empirical analysis. Particularly, it will be helpful to compare the accumulation of social capital by firms joining districts situated in two different geographic areas characterized by different opportunity costs of investing in the impure public capital.

To conclude, we argue that more attention to causality links and endogeneity should be paid when dealing with the issue at both empirical and conceptual levels. We think that only a joint theoretical-empirical effort can provide benefit for the SC framework. Otherwise, the risk is of focussing attention on not tested hypothesis as guidance for policymaking. We recommend further work on the applied direction, where there is great space for providing new evidence stemming from specific and micro-oriented survey studies.

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Appendix 1

(Equation of motion for λ).

The equation of motion for λ, $\dot{\lambda} = -\frac{\partial H}{\partial R_i}$, is:

$$\dot{\lambda} = -\frac{\partial H}{\partial R_i} = -e^{-\rho t}\left[\frac{\partial B_i\left\lfloor (s_i + S_{\neq i}), \alpha_i R_i, I_{R_i} \right\rfloor}{\partial (s_i + S_{\neq i})}\beta_i + \frac{\partial B_i\left\lfloor (s_i + S_{\neq i}), \alpha_i R_i, I_{R_i} \right\rfloor}{\partial R_i}\alpha_i\right] + \delta\lambda(t)$$

from which:

$$\frac{\partial \lambda}{\partial t} - \delta\lambda = -\left[\frac{\partial B_i\left\lfloor (s_i + S_{\neq i}), \alpha_i R_i, I_{R_i} \right\rfloor}{\partial (s_i + S_{\neq i})}\beta_i + \frac{\partial B_i\left\lfloor (s_i + S_{\neq i}), \alpha_i R_i, I_{R_i} \right\rfloor}{\partial R_i}\alpha_i\right] e^{-\rho t}$$

The complementary function is:

$$\lambda_c(t) = Ae^{\delta t} \qquad (\textit{A arbitrary})$$

To find the particular integral we put:

$$\lambda' - \delta\lambda = -\left[\frac{\partial B_i(.)}{\partial (s_i + S_{\neq i})}\beta_i + \frac{\partial B_i(.)}{\partial R_i}\alpha_i\right] e^{-\rho t}$$

and:

$$\lambda(t) = -De^{-\rho t}$$

$$\lambda'(t) = \rho De^{-\rho t}$$

$$\rho De^{-\rho t} + \delta De^{-\rho t} = \textit{left side}$$

From which:

$$D = -\frac{\left[\frac{\partial B_i(.)}{\partial (s_i + S_{\neq i})}\beta_i + \frac{\partial B_i(.)}{\partial R_i}\alpha_i\right]}{(\rho + \delta)}$$

$$\lambda_P = -De^{-\rho t}$$

The particular integral, hence, is:

$$\lambda_P = \frac{\left[\frac{\partial B_i(.)}{\partial (s_i + S_{\neq i})}\beta_i + \frac{\partial B_i(.)}{\partial R_i}\alpha_i\right]}{(\rho + \delta)} e^{-\rho t}$$

The sum of the complementary function and the particular integral then constitutes the general solution of the complete equation:

$$\lambda(t) = Ae^{\delta t} + \frac{\left[\frac{\partial B_i(.)}{\partial\left(s_i + S_{\neq i}\right)}\beta_i + \frac{\partial B_i(.)}{\partial R_i}\alpha_i\right]}{(\rho+\delta)} e^{-\rho t} \qquad (1A) \qquad (A \text{ arbitrary})$$

From the transversality conditions ($\lambda(T)$)=0), we can assert that in T:

$$0 = Ae^{\delta t} + \frac{\left[\frac{\partial B_i(.)}{\partial\left(s_i + S_{\neq i}\right)}\beta_i + \frac{\partial B_i(.)}{\partial R_i}\alpha_i\right]}{(\rho+\delta)} e^{-\rho t}$$

from which:

$$A = -\frac{\left[\frac{\partial B_i(.)}{\partial\left(s_i + S_{\neq i}\right)}\beta_i + \frac{\partial B_i(.)}{\partial R_i}\alpha_i\right]}{(\rho+\delta)} e^{-(\rho+\delta)T}$$

Hence, substituting in equation (1A), we get equation (12):

$$\lambda^*(t) = \frac{\left[\frac{\partial B_i(.)}{\partial(s_i + S_{\neq i})}\beta_i + \frac{\partial B_i(.)}{\partial R_i}\alpha_i\right]}{(\rho+\delta)} (e^{-\rho t} - e^{-(\rho+\delta)T+\delta t}).$$

Appendix 2

(Equation of motion for R_i).

The equation of motion for R_i, $\dot{R}_i = \frac{\partial H}{\partial \lambda}$, is:

$$\dot{R}_i = \frac{\partial H}{\partial \lambda} = \frac{\partial R_i}{\partial t} = I_{R_i} - \delta R_i$$

The complementary function is:

$$R_{i_c}(t) = Ae^{-\delta t}$$

and the particular integral is:

$$R_{i_P} = \frac{I_{R_i}}{\delta} \qquad (\delta \neq 0)$$

The sum of the complementary function and the particular integral then constitutes the general solution of the complete equation:

$$R_i^*(t) = Ae^{-\delta t} + \frac{I_{R_i}}{\delta} \qquad (A \textit{ arbitrary})$$

Moreover, by setting t=0 in this result, it is easily shown that $A + \frac{I_{R_i}}{\delta}$ represents the initial stock of $R_i (= \bar{R}_i)$.

Hence the optimal state path is:

$$R_i^*(t) = \left(\bar{R}_i - \frac{I_{R_i}}{\delta}\right)e^{-\delta t} + \frac{I_{R_i}}{\delta}.$$

Appendix 3

Table A.1 – A comparison between sample and population (year 2000)

	POPULATION(*)				SURVEY			
	Firms		Employees		Firms		Employees	
	N.	%	N.	%	N.	%	N.	%
Final firm	35	50.0	3,114	85.1	18	45.0	1,812	77.2
Sub-contractor	35	50.0	546	14.9	22	65.0	536	22.8
Total	70	100.0	3,660	100.0	40	100.0	2,348	100.0

Source: Baracchi and Bigarelli, 2001

Table A.2 – The distribution of final firms by employees class (year 2000)

	POPULATION(*)				SURVEY			
	Firms		Employees		Firms		Employees	
	N.	%	N.	%	N.	%	N.	%
0-49	24	68.5	461	14.8	12	66.8	184	10.2
50-249	7	20.0	692	22.2	3	16.6	304	16.8
>249	4	11.5	1,961	63.0	3	16.6	1,324	73.1
Total	35	100.0	3,114	100.0	18	100.0	1,812	100.0

Source: Baracchi and Bigarelli, 2001

Table A.3 – The distribution of sub-contractors by employees class (year 2000)

	POPULATION(*)				SURVEY			
	Firms		Employees		Firms		Employees	
	N.	%	N.	%	N.	%	N.	%
0-9	11	31.4	50	9.2	7	31.8	23	4.3
10-19	15	42.9	196	35.9	9	40.9	120	22.4
>20	9	25.7	300	54.9	6	27.3	393	73.3
Total	35	100.0	546	100.0	22	100.0	536	100.0

Source: Baracchi and Bigarelli, 2001