Faculteit der Economische Wetenschappen en Econometrie

Serie Research Memoranda

Measuring Network Externalities: Their Role on Corporate and Regional Performance

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Research Memorandum 1993-61

December 1993

vrije Universiteit *amsterdam*

MEASURING NETWORK EXTERNALITIES:

THEIR ROLE ON CORPORATE AND REGIONAL PERFORMANCE

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Paper presented at the 33rd European Congress, held in Moscow, Russian Federation, 24-27 August 1993

1. Introduction

In recent years much attention has been devoted to the diffusion and adoption processes of new information and communication technologies (ICTs). The interest in these technologies is originating from the importance they have assumed in the process of defining competitive advantages among firms and comparative advantage among regions.

The aim of the present paper is to offer analytical and policy issues to be investigated by way of a research agenda - rather than to present results of completed research - on diffusion (and adoption) processes of information and communication technologies. This agenda is a result of a broader strategic research project, in which the primary subject of study is the phenomenon of network externality, and its effects on the performance of firms and regions. This concept has recently been introduced by industrial economists as the main explanation of diffusion processes of interrelated technologies. The basic idea at the basis of all studies dealing with network externalities is that the rate of growth in the demand for interrelated technologies is dependent on the number of subscribers or clients already using that specific technology.

From this simple, yet fundamental, observation a series of theoretical and empirical analyses have followed, trying to conceptualise and prove empirically the significance of network externalities. Up to now, the concept has been widely studied and applied, especially with a view on measuring the impact that it has on the utility function of each subscriber or client. In essence, the basic concept stems from the strong interdependence which exists in the utility function of each potential subscriber to join the network, making the decision highly dependent on the behaviour of others.

The concept of network externality has been applied in a number of different research fields, so that at first sight the literature on network externalities suggests that many issues have been analysed under the label "network externality", which in reality are very different from one another in their nature and in the consequences they provoke on the market structure.

The paper is sub-divided into two parts. The first part is devoted to the analysis of the network externality concept and to the way it has been covered in the economic literature. This part is useful for both providing the reader with a structural framework of the literature on network externality and identifying the still uncovered field of research on which our study will mainly concentrate its attention.

The second part is primarily devoted to present the first conceptual and methodological approaches to this as yet unexplored field of research, dealing mainly with the impact that network externalities have on the industrial and regional performance. In particular, our main research question addresses the question whether network externalities provoke an increase in the productivity of firms and regions. More precisely, this second issue will try to answer the question whether:

- network externalities can be measured at the industrial performance level;

- network externalities can be measured at the regional performance level;

- regions have the possibility to gain from these network externalities.

These questions which have not been tackled before deserve no doubt much more theoretical and empirical reflection. In the light of the previous remarks, the second part of the paper provides a conceptual framework (Section 3), a mathematical model (Section 4), a methodological approach to network externalities measurement (Section 5) and a research framework for a future applied research in this field (Section 6).

2 . The Concept of Network Externality

Since 1974 with Rohlf's paper on network externality, this concept has become the subject of many studies interpreting it as a fundamental and strategic issue in the diffusion of new technologies (Allen, 1988 and 1989; Antonelli 1989 and 1992; Bental and Spiegel, 1990; Cabral and Leite, 1989; David, 1985 and 1991; Hayashi, 1991; Katz and Shapiro, 1985; Markus, 1989).

The name "network externality" stems from the well known economic concept of externality. In economic theory an externality is said to exist when an external person to a transaction is directly affected (positively or negatively) by the events of the transaction.

The concept of "network externality" is related to a simple but fundamental observation that the user-value of a network is highly dependent on the number of already existing subscribers or clients. This means that the choice for a potential user to become a member of the network is dependent upon the already existing number of subscribers or clients. This basic but crucial statement has strong implications not only on the development trajectories of new networks, but also on some crucial elements such as tariff structure, network interconnections, standardisation processes, optimal dimensions of networks and internetwork competition. In other words, the existence of network externality has some far reaching consequences for the actual operation and policy choices regarding networks. The notion of network externality is thus essentially related to the value of the network, depending on the already existing number of subscribers. This (varying) benefit of a network for a client is thus different from the given cost of access to the network for the advantage which an individual receives and does not pay once he joins the network.

From this perspective network externalities are the economic motive for the adoption of and entry to the network and are becoming the essential explanation for the diffusion of new interrelated technologies. Firms' decisions to join a new network depend primarily on the number of already existing subscribers in the network and not solely on the cost of purchasing the technology itself.

The previous observations can be illustrated by the supply- demand curve in Figure 1. In this figure, the individual demand curve on the market, labeled D (apparent), represents the benefits that subscribers receive from joining the network. These benefits are fully paid by the subscribers via the tariff system of a telecommunication network. If the individual demand, D (apparent), is interpreted in this way, it is too low since not all benefits subscribers can achieve by joining the network are properly represented. The higher demand curve D (real) takes into account the non-paid advantages subscribers receive joining the network, i.e. network externalities are taken into account, thus P_* shifting the equilibrium point from q_0 to q_1, representing the intersection point between demand (real) and supply.

The new price P_1 is higher than P_*, because it is the result of the initial market price of the service (P_*) and all value- added effects of producing the marginal unit of the service, i.e. the aggregate users value of the new subscriber. Thus P_1 reads as:

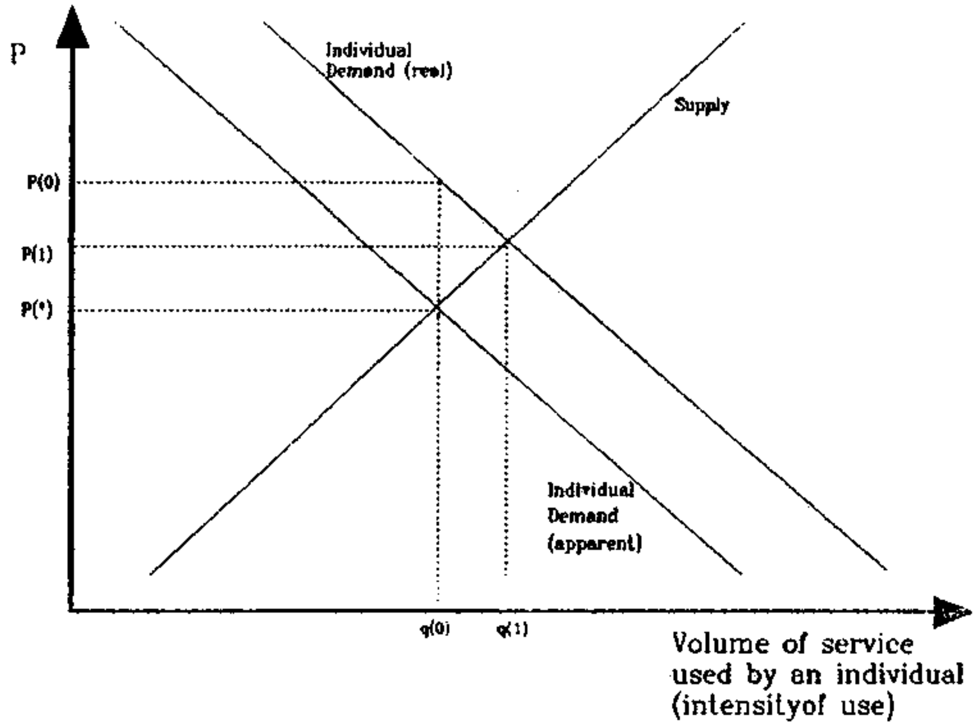
$$P_1 = P_* + Se$$

where Se is the new subscriber's effects on the network value.

It is clear that optimal output requires an expansion of market output from q_0 to q_1 at which point marginal cost is equal to marginal social benefit.

The market equilibrium is in this case "disturbed" by the existence of a positive consumption network externality. The diagram in Figure 1 is drawn on the basis of an infinite technological capacity of the network, which justifies the steadily increasing profit for suppliers with additional consumers. Clearly in case of fixed networks (i.e. networks with constant technological capacity), some strong <u>negative consumption network externalities</u> may arise because the quality of communications and the rate of failing contacts are affected by congestion (Amiel and Rochet, 1987). In the presence of network externality in a market equilibrium, network solutions are non-optimal, the market may fail, and resourse allocation implications arise.

Fig. 1. The effects of network externalies on market equilibrium



Source: Hayashi, 1992

The telecommunication industry seems to offer the most appropriate context for studing network externalities and all economic consequences they provoke. The telecommunication system is in fact characterised by some strategic features, which can explain the existence of network externality, namely:

a) interdependence of consumer's utility, since the choice of a person to join the network is dependent on the behaviour of other clients;

b) interdependence between potential adopters and users of a new technology, since the latter may create for the former a reduction of search costs and market prices for complementary inputs, maintenance and skills stemming from their experience in using the technology already adopted, through dynamic learning processes;

c) interdependence between potential users and suppliers. On the one hand, the know-how and the experience accumulated by suppliers acts as a driving force in the adoption process. In fact, the adopting firms are facilitated in the search for know-how and complementary inputs (i.e. organisational strategies) thanks to precise "guidelines" provided by the suppliers. On the other hand, the higher the number of adopters, the broader the know-how of the supply will be. In other words, the relationship between supply and demand generates cross-learning processes, via the bridging between demand needs and supply knowledge;

d) interdependence between producers of complementary technical components and products in the telecommunication "filiere". The interrelation of sub-markets may provoke externalities, since the profit function of a producer is influenced by the economic transactions of other producers whose behaviour
affects the market prices of intermediary inputs;

e) interdependence between users' productivity, since the advantages obtained by a firm on its productivity are dependent on the number of already networked firms. In fact, the advantages obtained through the use and exploitation of these technologies are a function of the number of firms already using them.

While the first three features affect the utility function of a final individual user, the last two act on the productivity of firms, the telecommunication service acting as an input factor in the production function. Moreover, these features are related to both telecommunication manufacturing firms and service providers (the telecommunication production sphere) and to the adopting firms using these technologies as final or intermediate products (the telecommunication use sphere).

Figure 2 presents a typology of network externalities on the basis of the previous telecommunication market features. In the top-left quadrant of Figure 2, network externalities are related to the telecommunication adopters and are the typical consumption network externalities acting on the utility function of an individual final user. Here the interdependence among utility functions of users of telecommunication networks is at the basis of the traditional network externality concept. Telecommunication demand is more and more explained through interrelated decision making processes of adopters, a situation which influences the growth rate of the telecommunication demand.

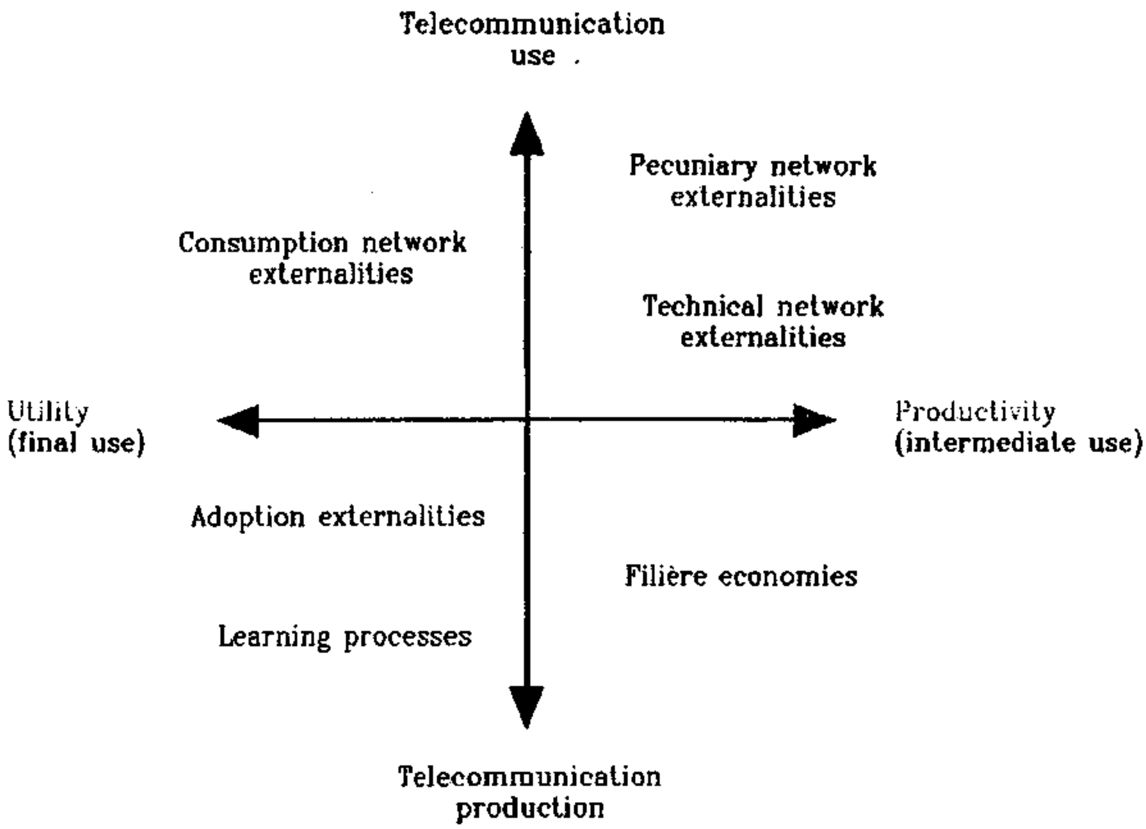
A well-known example of consumption network externalities is the so called hardware/software paradigm (Katz and Shapiro, 1985 and 1986), regarding the strong interdependent preferences dominating the choice of a consumer to buy a certain kind of hardware. In the words of Katz and Shapiro (1985, p. 424):

> ".... an agent purchasing a personal computer will be concerned with the number of other agents purchasing similar hardware, because the amount and variety of software which will be supplied for use with a given computer is likely to be an increasing function of the number of hardware units that have been sold".

Also in this case, the benefit that a consumer derives from the use of a good is an increasing function of the number and behaviour of other consumers, in this case the fact that they buy compatible items.

Figure 2

A Typology of Network Externalities



At the users side, another kind of network externalities is present, which is called in the literature adoption externalities (Antonelli, 1992). In the diffusion processes of these technologies a crucial role is also played by collective learning processes, like in all cases of complex technologies. Again, these processes seem to hide a sort of network externality mechanism, because of non-paid advantages that potential users of the technology gain from the experience of old adopters. For potential adopters, non-paid advantages may emerge from lower search costs of complementary inputs, or from specific know-how on how to use and maintain the technology, stemming from consolidated experience on the use of these technologies accumulated by previous adopters.

However, these features, recently interpreted as an externality mechanism (Antonelli, 1992; David, 1992), may be in reality only explained through the traditional concept of dynamic learning processes, similar for their effects, but different in nature from the traditional concept of network externalities. Learning processes stem in fact from the concept of dynamic economies of scale (Spence, 1981), while network externalities stem from the non-paid benefits obtained by interdependent mechanisms.

The same can be said for the case of telecommunication product firms acting on the utility function of telecommunication users through cross-learning processes (bottom-left quadrant). Again, users benefit from these learning processes, through dynamic economies of scale, which are different in nature from the concept of network externalities.

Network externalities in the telecommunication sector do not only affect the final user, by impacting on his utility function. In the telecommunication industry also the intermediate user (or supplier) acts under certain particular features (bottom-right quadrant).

As far as the telecommunication technologies production is concerned, telecommunication networks are built upon an array of interrelated technical components such as terminals, transmission facilities and switching equipments, as well as intermediate outputs in the extremely complex telecommunication "filiere". The interrelation exists both in vertical relationships (intermediate inputs for telecommunication outputs) as well as in horizontal final products markets (advanced terminals whose development stimulates value added services such as Minitel, and electronic mail).

In both horizontal and vertical interrelationships the behaviour on the market of each economic agent (reduction of prices, new market niches) affects positively the profits of the other interconnected producers, generating what can be interpreted as network externalities. However, these kinds of advantages are typical filiere economies, stemming from a vertical integration in a sector. In other words these advantages may be associated with traditional "economies of scale" generated in a vertically or horizontally strong market relationship (bottom-right quadrant in Figure 2).

Another extremely appropriate example of these kinds of "filière" economies is presented by the hardware/software industry. Computers (hardware) and programs (software) have to be used together, and the greater the sales of the hardware, the higher the profits for software producers will be, via the technical interconnectivity of the two markets.

Finally, an interesting situation concerns the interdependence among productivity of different intermediate users. In this case, we can again speak of network externalities, this time related to the use of the service as an input factor for other products, thus having an impact on the productivity level of firms (top-right quadrant in Figure 2). In this framework, both the concept of pecuniary (network) externalities (Scitovsky, 1954) and technical (network) externalities (Meade, 1954) may be useful. Pecuniary externalities are provoked whenever the profits of one producer are affected by the actions of other producers. In other words, pecuniary externalities act on input factors decreasing their costs and thus having positive effects on the output. This category differs from the "technological external economies", defined by Meade (1954) as those advantages obtained by a firm on its output through the non paid exploitation of the output and input factors belonging to other firms. The latter category sees external economies as a peculiarity of the production function, i.e. these external economies act on input factors productivity. Through the increase in the input productivity these external economies influence positively the corporate output.

For telecommunication network users, the use of the network generates an increase in input productivity (or profit advantages), only partially covered by the costs of joining the network. The non-paid advantages obtained by a subscriber joining a network provoke unintended positive effects on the economic performance of the new subscriber. Thus, if network externalities represent the (economic) motive for entering the network, a better economic performance of firms is the (economic) effect they produce at the productivity side.

From the above observations we conclude that in the ICT sector the concept of network externality is to be related only to telecommunication (final or intermediate) users (in Figure 2 only the upper part). In recent years, the broad definition given to network externalities has expanded it towards network externalities in the production sphere (manufacturing firms and service providers), thus losing the precise meaning of the concept and substituting it for more traditional economic concepts.

While consumption network externalities in the context of the use of telecommunications (top-left quadrant), as well as adoption externalities (learning processes) (bottom-left quadrant) and "filiere" economies (bottom-right quadrant) have been widely identified and analysed in the literature, a still unexplored field of study is the measurement of the effects of network externalities on the productivity side. The non-paid advantages of users joining a network are reflected in the performance of these subscribers, via the reduction of input factor costs or the increase in their productivity.

These kinds of network externalities have not or hardly been explored, and neither the effects they generate. This is the area addressed in the paper by providing a conceptual and methodological framework for dealing with the basic strategic question whether firms and regions can gain from network externalities effect.

3. Industrial and Spatial Performance of Network Externalities

Our basic research questions are related to the linkage between network externalities and industrial and regional performance. In particular, our main task is the analysis of the question whether or not network externalities may be measured in terms of industrial (i.e. micro-meso) and regional (i.e. meso-macro) performance. Such a research question is fraught with many empirical difficulties of a methodological nature, to be dealt with in the next section. At the purely conceptual level however it is easier to envisage a positive relationship between network externalities and the corporate output.

The access to a network and the non-paid advantages a firm gets by joining the network play a crucial role in the performance of firms, primarily via an increase in productivity. This assumption is evident, since a firm may obtain advantages from being networked, without paying for it a marginal price.

These advantages may be classified in terms of direct and indirect advantages. The definition of direct advantages is related to the fact that the advantages a firm gets via a network directly affect (positively) the productivity of a firm: more synergies among actors (in a static perspective), and the achievement of new markets (in a dynamic perspective). Other advantages may be achieved via a network, which indirectly affect the productivity of firms: information provision induced via network interconnection (in a static perspective), and complementary assets (in a dynamic perspective). All these advantages are generated by the existence of a physical linkage on the network, by means of what we call "positive network externalities". These advantages are expected to generate, directly or indirectly, a <u>positive effect on the performance of firms</u>.

The achievement of a higher economic performance by exploiting benefits derived from joining a network is what we call an "economic symbiosis" effect. The capabilities of exploiting these advantages is far from being equal among firms and is mainly dependent on the way these technologies are used. Firms can in fact achieve a status of cooperation via a network, which means the exploitation of <u>mutual reciprocal network externalities</u>. Nevertheless, it is also possible that a different kind of relationship is established, more dependent on a hierarchical structure among firms, which could generate a sort of dependency of a firm to another, and a certain kind of "exploitation" takes place. In this case, a unilateral network externality effect is generated.

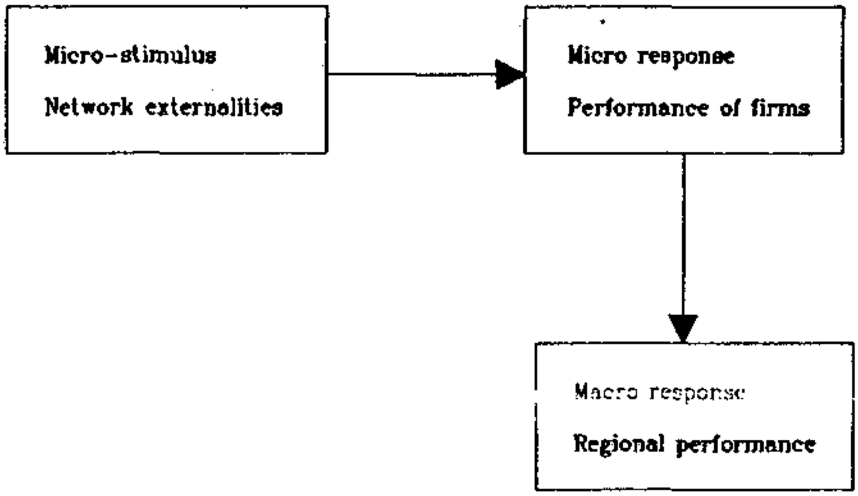
Thus, an interesting question in network analysis is the identification and definition of those firms which are more able to exploit network externalities. In other words, distributive effects of network externalities among users is an interesting aspect to be invastigated.

Our framework is based on many studies which have been developed on the basic idea that technological change and innovation are the main driving forces for the improvement of firms performance, via an increase in productivity (Stoneman, 1983 and 1992). All literature dealing with innovation diffusion processes captures the linkage between innovation and better performance, although it is still fair to state that the majority of the empirical work on this topic has not yet caught up with theoretical advances.

Although there may be similarities in effects reflecting a better performance of firms, the causes or main reasons for this phenomenon may have completely different origins and a completely different nature. Without denying the existence of other driving forces improving the performance of firms (i.e. international market developments, better marketing strategies, etc.), the present paper aims to focus only on one distinct cause of increased performance, viz. the network externality phenomenon.

At the conceptual level, the framework rests thus on the assumption that the main micro-stimulus explaining adoption processes of advanced telecommunication technologies is the existence of network externalities (Figure 3). Our analytical framework proceeds then, by assuming that even regions can benefit from network externalities effects. In fact, the basic idea is that the existence and exploitation of network externalities are not confined to the firm level. In fact, the presence in a region of firms being able to exploit the advantages of network externalities for their performance determines - in aggregate terms - the positive effects on regional performance, a phenomenon we will call spatial symbiosis.

Fig. 3 Conceptual Framework



The spatial symbiosis is interpreted as the (non zero) sum of the (positive) effects on the firms performance generated by firms through the exploitation of network externalities. The positive effects at a firm's level, in fact, are expected to reflect their positive influence at the level of the environment in which they perform. Thus, in economic terms we expect a region to have the possibility to gain from network externalities, by exploiting (non-paid) advantages stemming from its participation in the network. At a macro level these advantages may be described as the achievement of:

a) spatially dispersed information;

b) new geographic market areas;

c) complementary know-how from different specialised economic areas;

d) additional specialised input factors from other regions.

As is the case at the firm level, also at the macro level the capability of exploiting the spatial symbiosis is not equally distributed. Essentially, a spatially varying capability of exploiting network externalities of firms can be ascribed to two components, namely the structural component and the production milieu component.

These two elements have in recent studies been identified as the main issues for the explanation of different degrees of regional innovativeness (Davelaar, 1991). To a certain extent the same approach can be developed for the analysis of the different spatial capacities of receptivity, i.e. the capacity of "advantages appropriability". We may argue that the spatial symbiosis is highly dependent on the extent to which:

a) firms and sectors in a region are able to exploit network externalities. In other words, the regional structural component of firms and sectors with a high capacity of exploiting the economic symbiosis will be one of the critical determinants of the spatial symbiosis;

b) the local (spatial) capacities to exploit network externalities. In fact, the so called "production milieu component" plays a role in the definition of the spatial symbiosis. Identical firms, in fact, can be able to exploit network externalities in different ways, according to their location in space.

The traditional macro conditions presented by the literature as explanatory factors for a region to be more innovative than another may be only partially applied here. Davelaar (1991) points out four clusters of "production milieu" variables in his explanatory framework of regional and spatial incubation analysis:

a) agglomeration of (different types of) firms, from which the possibility to exploit agglomeration economies depends;

b) demography and population structure, i.e. the "market area" or the structure of the labour market;

c) information infrastructure, which guarantees to the area the availability of information, a situation always thought of as an important stimulus for the generation and adoption of information;

d) physical and institutional infrastructure. The presence of public infrastructure, such as modern transport and telecommunication networks, have always been thought of as important factors for the innovativeness of a region.

The "production milieu" variables related to the development of the spatial symbiosis have to be identified precisely in those spatial variables defining both the adoption processes and - especially - the exploitation processes of these technologies. These macro conditions are expected to be:

a) agglomeration of different innovative firms. In this case the willingness to imitate and to "copy" the innovative use of new technologies from already innovative firms is stimulated. Moreover, the spatial clustering of firms gaining market shares for the exploitation of network-based innovations may also turn out to lead to the attainment of a higher share of the market;

b) the population structure. As for the degree of innovativeness in general, also the innovative use in a region depends on the labour market present in the area, and on related traditional spin-off effects which can facilitate learning processes on the use of new technologies among firms;

c) the presence of a firms' service sector. Instead of underlining the importance of the information infrastructure, in the case of the exploitation of the new telecommunication networks and services the existence of consultancy firms for organisational aspects becomes crucial, because of the high degree of organisational changes required for a firm once advanced telecommunication technologies are exploited in an innovative way. The cohesion and interrelation between technology and organisation is in fact of strategic importance in order to exploit new technologies in an innovative way, and not just to introduce them as substitution means of old technologies.

It is in central areas that the above macro-conditions are usually present, as is suggested by much literature. In fact, central areas can exploit:

a) an advanced labour market, in terms of technical, managerial and organisational know-how and capacity to innovate;

b) collective learning processes that enhance the capacities to exploit network externalities, through learning processes in the use and exploitation of these technologies;

c) a wide service market, especially corporate organisational consultancies, becoming crucial for the integration of new ICTs with the organisational structure of firms, and - at the territorial level- with the "vocations industrielles" of the area.

Seen from a static perspective, spatial symbiosis would be exploited by central areas, which are more likely to be the seedbed areas for the location of innovative firms (structural component) and more local economic characteristics justifying their better capacities to exploit network externalities (production milieu component).

The above concepts of "economic symbiosis" and "spatial symbiosis" show some similarity to older concepts of "growth poles" (Perroux, 1954) and "growth centres" (Boudeville, 1968), respectively. A growth pole was supposed to operate in an economic network space (without a clear reference to its geographic location), whereas a growth centre was regarded as a geographical concentration of economic activities as a result of agglomeration economies. Both explained regional and spatial development starting from the consideration of a "key" production unit generating a set of polarisation and development effects, via Keynesian income multiplier effects, direct and indirect input-otput effects, and spatial advantage effects.

Although our framework suggests that a set of polarisation and development effects arises via the physical linkage of firms, the original causes of the generation of multiplier effects are of different nature. While the "growth pole" theory defines the reasons of development in the existence of key production units generating a set of attractive factors, in the spatial symbiosis approach the cause of generation of these development effects is the physical ICT connection with other firms. This relation, in fact, generates a set of synergies, via exchanges of know-how and information, which improve the productivity of networked firms. At the aggregate level, greater productivity of firms located in the same region is measured in terms of a better aggregate performance. When the linkage takes place at an inter-regional level, the effects it produces may also be reflected in import and export implications.

4. A Theoretical Model for Network Externalities Measurement

In this section we will present a theoretical model for network externalities measurement. In order to prove the validity of the "economic and spatial symbiosis" framework, it is in fact of fundamental importance to find a methodology able to measure network externalities on corporate and regional performance. Our idea is to develop a theoretical model acting as a bridge between our conceptual assumptions and our empirical analysis. In fact, from this theoretical model some crucial statements are highlighted, which have to be proved empirically. The model deals with a situation of mrket equilibrium in the presence of network externalities affecting the final output.

In the theoretical model we introduce the concept of "connectivity index". The degree of benefits received from a network externality is highly dependent, by definition, on the physical connectivity among firms. Thus, a connectivity index is of crucial importance in the analysis. A way of measuring this index with the help of graph theory is presented in section 5.

4.1. An equilibrium model with network externalities

The traditional model of cost minimisation under the assumption of a given output allows us to find the optimal mix of production factors K and L, minimising costs for a given output. In this section we introduce the assumption that firms may benefit from network externalities through a physical linkage with other firms. The hypotheses on which our model rests are the following:

a) there are only two symmetric firms in the market, acting simultaneously on the market. These firms are symmetric, i.e. their position in the market is similar;

b) the advantages firms get from being networked are embodied in more information received via the network. The network externality concept is present in our model by assuming that the volume of information firm A receives is dependent not only on the investments that firm A bears for being networked, but also on the investments undertaken by firm B. Thus, the volume of information firm A receives is more than the marginal costs firm A pays for having access to the marginal information unit.

The production function of firm A is then,

$$q_A^* = \eta\ K_A^{\alpha}\ L_A^{\beta}\ \gamma_A^{\delta} \tag{1}$$

where γ_A represents the connectivity index of firm A, being a γ_A function of what firm A invests in the network and what firm B invests in the network. If we assume a linear relation between the investments in a network and the connectivity index, we end up by having the fllowing linear equation in γ_A:

$$\gamma_A = \varepsilon_A\ N_A + \varepsilon_B\ N_B \tag{2}$$

under the assumption that $\varepsilon_A > \varepsilon_B$, because it is plausible to expect that the investment profitability in γ_A is higher for firm A than for firm B.

c) a third crucial hypothesis is related to the cost function. Unit costs of networking (C_{NA} for firm A) are a function of γ_A:

$$C_{NA} = F\ (\ \gamma_A) \tag{3}$$

It is realistic to expect a decreasing relationship between unit costs and γ_A. Because of learning processes and cumulative experience in the use of the network, marginal costs decrease if connectivity increases. There will be of course a level of fixed costs (C_{NA}). The cost function of networking is thus:

$$C_{NA} = \frac{C_{NA}^*}{\gamma_A} \tag{4}$$

The interesting question at this point is to find the new levels of K, L, and γ_A, guaranteeing the minimisation of costs for firm A. The solution method is similar to the traditional model of micro-economic production theory, taking into account the new production and costs functions. Firm A has the aim of minimising cost function, subject to a given production level:

$$\min C_A (K, L, \gamma) = C_{KA} K_A + C_{LA} L_A + C_{NA} (\gamma_A) N_A \tag{5}$$

$$\text{s.t.} \qquad q_A^* - \eta K_A^{\alpha} L_A^{\beta} \gamma_A^{\delta} = 0 \tag{6}$$

If we solve it using the Lagrangian function, we obtain

$$\begin{cases} \dfrac{\delta L}{\delta K_A} = C_{KA} - \lambda \alpha \dfrac{q_A^*}{K_A} = 0 & (7) \\[2ex] \dfrac{\delta L}{\delta L_A} = C_{LA} - \lambda \beta \dfrac{q_A^*}{L_A} = 0 & (8) \\[2ex] \dfrac{\delta L}{\delta N_A} = \dfrac{-N_A C_{N_A}^* \varepsilon_A}{(\varepsilon_A N_A + \varepsilon_B N)^2} + \dfrac{C_{N_A}^*}{(\varepsilon N_A + \varepsilon N_B)} - \lambda \delta \dfrac{q_A^*}{(\varepsilon N_A + \varepsilon_B N_B)} = 0 & (9) \\[2ex] \dfrac{\delta L}{\delta \gamma} = q_A^* - \eta K_A^{\alpha} L_A^{\beta} \gamma_A^{\delta} = 0 & (10) \end{cases}$$

The solution of these equations determines the level of K, L and N guaranteeing the maximisation of profits:

$$K_A = \frac{C_L \beta L_A}{C_K \alpha} \tag{11}$$

$$L_A = \frac{C_K \alpha K_A}{C_L \beta} \tag{12}$$

$$N_A = \left(\frac{C^*_{N_A} \, \beta}{\delta \, C_{LA} \, L_A} - 1 \right) \frac{a_B}{a_A} N_B \tag{13}$$

These levels of K, L and N represent the mix of the three production factors that guarantee the minimisation of costs for firm A. The difference with the traditional model is that the level of connectivity does not only depend on the choices of firm A, but also by what firm B decides. I n fact the level of investment on a network N_A is dependent also on the level of investments born by firm B. The present N_A is found with no respect for the choice of firm B. Thus, this means that, firm A minimises its production costs without taking into consideration the strategic choices of firm B. Because firm B behaves rationally, it will also have the same aim of firm A and will fix its mix of production factors at the level guaranteeing its costs minimisation. Firm B will change the level of investment in a network, N_B, until this level guarantees a profit maximisation. If firm B changes the level of N_B, this decision influences the level of N_A. Firm A will be obliged to reallocate its production function until the level of A guarantees a simultaneous costs minimisation for both firms A and B. Thus,

$$\gamma_A = a_A N^*_A + a_B N^*_B \tag{14}$$

where N_A and N_B are minimum.

This represents a Cournot equilibrium, where the two firms simultaneously achieve a profit maximisation. If one firm does not achieve the optimum solution, it could be inclined to reallocate its production factors in favour of a cost minimisation. This will oblige the other firm to change its equilibrium point. The game finds a stable solution only when both firms simultaneously achieve a cost minimisation point, given by the levels of K, L and γ_A defined before.

This theoretical approach shows some interesting implications for the existence of network externalities:

1) if the quantity of labour and capital decreases, the level of investment in the newtork increases;

2) if the level of investment in the network developed by firm B increases, the quantity of labour (or of capital) of firm A decreases, for a fixed level of investment in the network.

To verify our economic symbiosis framework, the first attempt is to see whether these relationships between network investments and quantity of capital and labour are true. Moreover, it is our aim to develop the same model for a sequential game where two asymmetric firms are present.

In this section we have spoken about a connectivity index, which enters the production function as a new input. In the next section we will present a way of measuring this index.

5. A Methodological Approach to Network Externalities Measurement

5.1. Connectivity and network externalities at a firm level

In order to demonstrate the validity of the "economic and spatial symbiosis" model, it is of fundamental importance to develop a methodology that is able to measure network externalities effects on the performance of firms and regions.

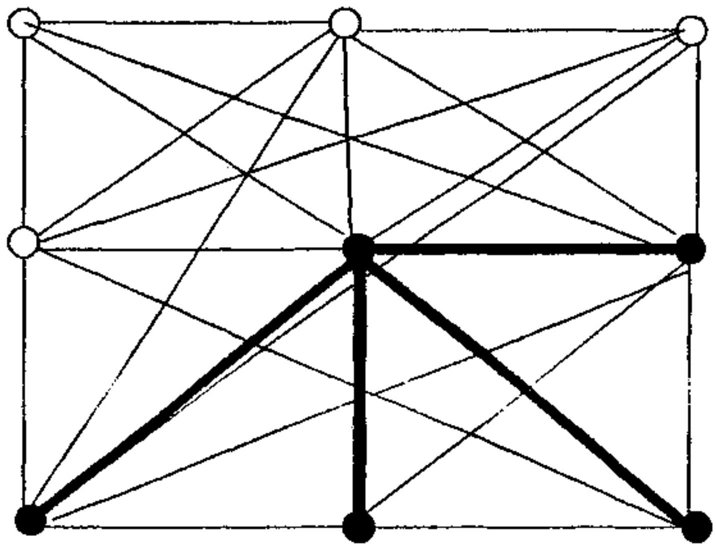
Up to now the concept of network externalities has been explained in terms of the positive and increasingly intensive relation between the number of subscribers and the performance of firms. The higher the number of subscribers, the higher the interest of a firm to join a network, and thus the better the effects on its performance. In reality, this definition is far too broad to explain the concept of network externality. In a static perspective the interest of a firm is not to join the highest possible number of firms connected via the network, but only the highest number of firms directly or indirectly related to the business activities of the firm. Thus, the decision of joining the network is not related to the number of firms already networked, but by the number of specific business-related firms already present in the network. The most obvious reason for entering a network is, in reality, the possibility of contacting relevant groups such as suppliers, customers or horizontally related firms in a more efficient and quicker way.

Connectivity is in fact a measure of a linkage between two or more firms in a network. The economic connectivity measures the economic relationships among firms. When these relationships are mediated via a telecommunication network, then we can also speak of physical connectivity. What we argue here is that there is a strong relationship between these two kinds of connectivity; in particular physical connectivity has no ground to exist if economic connectivity does not exist.

Figure 4 is a schematic representation of physical connectivity with the use of graph theory. If we represent firms as nodes, or vertices, and the physical linkages among them as arches, or edges, the outcome is a (undirected) graph of vertices and edges representing all potential physical communication (or contact) lines that firms can entertain among themselves.

As we have just mentioned, the real interest of firms, in a static world, is not to be linked to all other possible subscribers, but to achieve full connectivity among firms related to its business. If we represent in our graph these firms with a bold vertex, and their economic relationships with bold

Fig. 4. Undirected graph representing connectivity among firms



Legend: ○ Firms

● Business-related firms

Normal lines: possible physical connections among firms

Bold lines: physical and economic connections among specific "business-related firms" edges, the real matrix of first order relationships will emerge. With this matrix it is possible to measure the proportion of real physical connectivity of a certain firm with regard to potential [redacted] economic connectivity.

The physical connectivity is what generates network externalities. If the benefits a firm receives from physical connectivity is an increasing function of connectivity itself, then positive network externalities exist, a situation represented by the positive derivative of the benefit function (Figure 5). Thus so far we have described a way of measuring network externalities under the assumption of a static world. Figure 5 represents now a possible way of measuring static network externalities.

If we remove the assumption of a static situation, the potential linkages that firms are offered via a telecommunication network become of crucial importance. In fact, in a dynamic perspective, the interest of firms is not only to achieve static efficiency by developing better and quicker economic relationships with the already existing suppliers and customers. The purpose and aim of networking is related to the exploitation of other economic advantages, namely:

a) the achievement of new markets;

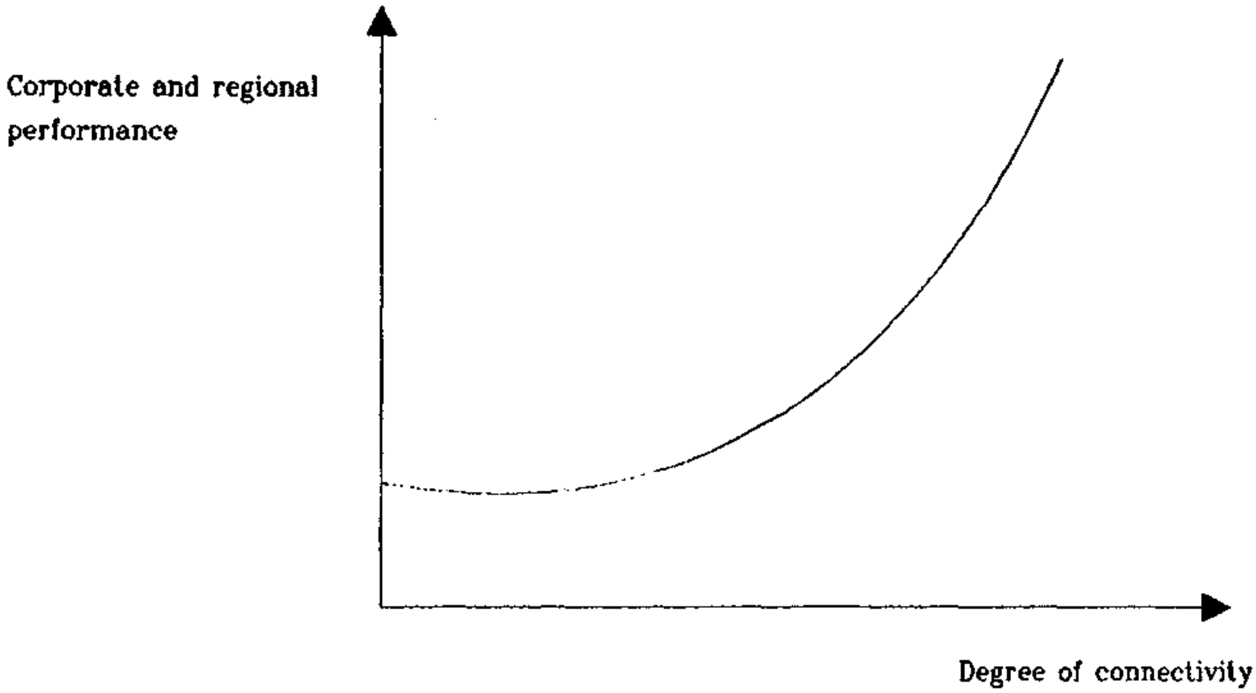
b) the development of product and process innovation, with the achievement of new and complementary technical, managerial and organisational know-how

c) the control on the development trajectories of the strategic complementary know-how, by mantaining and increasing all strategic information sources;

d) the achievement of higher quality in the intermediate products provided by suppliers, creating more competition among them , by increasing their number.

In order to achieve these economic advantages, the increase in the degree of physical connectivity is the crucial vehicle for establishing new economic relationships, by achieving a higher degree of integration among economic agents. The exploitation of dynamic network externalities is in this case dependent on firms' expectations about the degree of "cooperation" or complementarity of other firms. If they expect that other firms will be willing to cooperate, then the degree of physical connectivity will increase, and,

Fig. 5 Increasing relationship between the degree of connectivity and corporate and regional performance: positive network externalities



consequently, the benefits that firms receive from their connectivity.

Related to the exploitation of dynamic network externalities is the problem of competition among distinct and exclusive networks. Examples are for instance telex and telefax networks. Apart from going through a normal product life cycle, their evolution depends also on the intensity of use by other clients (i.e., the potential access a network offers to designated parties of a firm). (see also Rietvelt and al., 1992). This also raises the issue of compatibility of the technology of the network. If networks cannot be made compatible, they are by definition competitors and are facing fierce competition to their introduction and market penetration. It is an important issue to identify the degree of mutual openness of two "exclusive networks". The critical point is to define whether it is more convenient for an exclusive network to open the access to the members of other exclusive networks. The advantage of achieving a new information source is reciprocal in case of a compatibility of two former closed networks and thus the decision depends on the willingness to lose unique acccess to strategic information compared to the willingness to achieve new information.

An illustrative example is presented by the case of the flower network in the Netherlands, which is providing all strategic information on export market etc. to all flower suppliers who are a member. A great problem is now presented by the possibility of linking the national Dutch network to flower data base networks in other countries. The competitive behaviour of monopolising information is in contrast with the cooperative behaviour of joining a larger network with more competitors, but also better international market access.

The final decision of free access to a network depends on two kinds of expectations:

a) expectations on the role that firms already belonging to the network will play on the market. The stronger the firms are, the higher the degree of openness. In this case the already existing firms are expecting to play essentially a role of winner in a wider network;

b) expectations of the already existing firms in the network on the behaviour of firms which do not yet belong to the network. In this case, if expectations are linked to a competitive behaviour, rather than to a cooperative one, the possibility of opening the network is rather low.

In a dynamic context it is not always true that the higher the connectivity, the higher the benefits a firm can get. The explanations are twofold. The first reason is that in a dynamic context, power relationships have still to be defined between firms with new relationships and the uncertainty about the economic power relationship which will be defined does not allow for the definition of the advantages one can get by being linked to a network. The second reason is that network externalities exist, if a business relation is established before the physical linkage among the two firms. Like in the static case network externalities are in fact generated by connectivity, where this connectivity is the result of an economic interest rather than a pure physical communication possibility.

5.2. Connectivity and network externality at a regional level

In the previous section we have suggested a methodological approach to the measurement of economic symbiosis. For the sake of coherence in our analysis section 5.2 will be devoted to the explanation of the methodology for measuring the effect that network externalities have on the regional performance. The approach is the same as the one for the economic symbiosis, i.e. the identification of a connectivity index, representing the relationships that firms have within that region and with firms in other regions. Using the same logic as in the case of the firm level, the connectivity among firms within the same region and outside can be measured by means of graph theory. A positive derivative between the connectivity index and the regional performance would explain the existence of network externalities effects.

With the use of this method, the idea is to measure the relationship between network externalities and regional development. We may then envisage some plausible results, in the sense that the spatial symbiosis is expected to be higher:

- among regions of different economic development. Especially in the case of backward regions, the effects of network externalities on regional performance are intensive if the linkage is with advanced regions, since the linkage with these regions may fill the gap of local missing resources;

- among regions with advanced development, since synergies emerge from the exploitation of complementary inputs; from economies of scale or scope stemming from the cooperation in a market and from the achievement of a critical mass to afford financially heavy innovation projects.

In the case of both the corporate and the regional level, various analysis questions remain on some methodological aspects.

The first open question is related to the measurement of network externalities via a connectivity index which measures only direct connections. In other words, only first order connectivity is measured via our method, while second and higher order connectivity linkages are not taken into account. The choice of measuring a first order connectivity index requires in reality a careful choice. Second and third order connectivity loses the straightforward impact first order connectivity has on the production function, because the most strategic relationships which matter on the productivity of a firm are the direct relationships with suppliers and customers. Direct relationships among suppliers or customers of the same firm, representing what we call second and higher order connectivity for that firm, do not have the same direct relation with the performance of that firm.

A second open question which arises from the method we presented to measure network externalities is that a connectivity index does not take into account the intensity of information flows. While in the case of the first question we might disregard the importance of indirect connections of a firm on its performance, in the second case it is more difficult to avoid the problem. The intensity of use of a network, and not only its access, has inevitably an impact on the corporate performance.

The intensity of flows between regions may in principle be measured with the use of spatial interaction models, such as gravity models, represented by two principal nodes, and by a factor measuring the obstacles raised by the distance between the two locations:

$$T_{ij} = K \cdot W_i \cdot W_j \cdot f(c_{ij})$$

where:

T_{ij}: measure of the interaction between i and j
W_i: potential size node i
W_j: potential size node j
$f(c_{ij})$: cost of interaction between i and j

This model is defined as a meso/macro level. In the case of physical connectivity via a telecommunication network between two regions, the cost of interaction is represented by both entry costs and use costs of the network. These costs explain why, although by definition network externalities generate greater performance, there still might be a low intensity of use of a network. A logic explanation of this behaviour is represented by transaction costs which have to be born, being measured in terms of entry costs and users costs (phychological, financial, etc.). Shadow costs of the transaction, i.e. all costs which have to be born in a transaction process towards the adoption and use of these technologies, can in this case be measured and used as a measure of costs of interaction between regions. This model might be helpful especially at the spatial network level, but it cannot be used for the firm's behaviour. In most cases, the description of a firm to join and to use a network is of a discrete nature, so that - in case of a sufficient micro data base on firm behaviour - also discrete choice models can be used. Such models are compatible with spatial interaction models at a meso/macro level (see Nijkamp and Reggiani, 1992).

6. Conclusions: A Research Agenda for the Future

The present paper provides a first effort to offer a framework for the definition and measurement of network externalities on corporate and regional performance. Clearly, much work still needs to be done. The research agenda for the future requires an empirical analysis of the above methodological approach to the measurement of network externality.

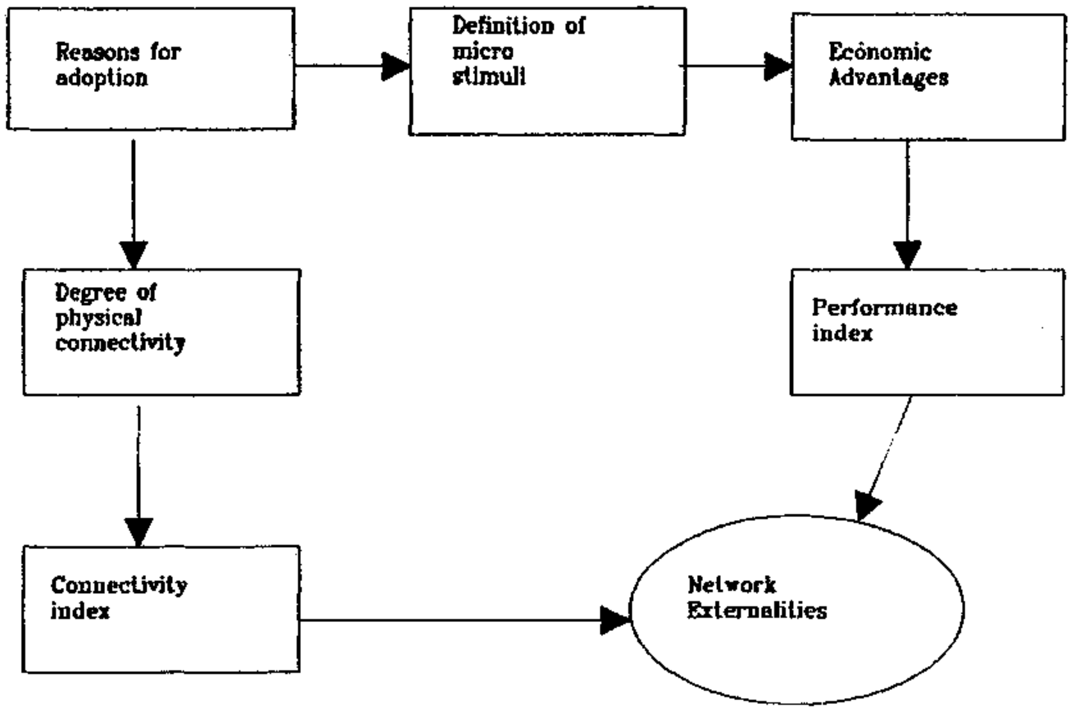
For this purpose, at present an empirical analysis is carried out, regarding the evaluation of the so called STAR project of the European Community. This project is devoted to the implementation of advanced telecommunication technologies in the less developed regions of the Community. The empirical investigation is now trying to look at the impact that the implementation of advanced telecommunication technologies have in Southern Italy in terms of both the competitiveness of local firms and the regional development. Data are collected via a survey questionnaire on the adoption processes and advantages in small and medium firms in Southern Italy. In a more general setting, the idea is to carry out an evaluation of the effects that the development of advanced telecommunication technologies have provoked on the less developed regions of the Community.

The empirical analysis is carried out through in-depth interviews with corporate users, with a structured questionnaire.

The logic structure of the questionnaire is presented in Figure 6, where the underlying logical framework of the empirical analysis is summarised. The first idea is to test whether the micro stimulus generating the adoption process may be associated with the network externalities effect. For this purpose, the first part of the questionnaire deals with the reasons and bottlenecks for the adoption of these technologies. The degree of adoption leads to the identification of the degree of physical connectivity of that particular firm, and to the possible identification of a connectivity index (representing the proportion of the real connectivity on the potential connectivity).

The following part of the analysis deals with the economic advantages obtained by these firms from the use of these advanced telecommunication

Fig. 6 Structure of an ICT Impact Analysis of Economic and Spatial Symbiosis



technologies and services in terms of more economic relationships with other firms, and in terms of better economic performance. If a positive relationship is envisaged between the connectivity index and the economic advantages of a firm, network externalities have an incidence on the dynamics of the economic and regional performance.

This kind of empirical analysis is relevant for two reasons. The first reason is the as yet very low level of adoption of these advanced technologies. This helps the measurement of network externalities as the motive for entering the networks, since the concept of network externality is especially influencing the first phases of the adoption process. In the first phases of development, the network externality phenomenon is more easily emerging and measurable.

A second reason for this choice is that this project is devoted to the development of advanced telecommunication technologies in the most backward regions of the Community, with the aim of inducing regional and local sustainable development. The evaluation of the real effects of ICTs on the regional development is more evident and more realistic to perform than in more developed regions, where the marginal benefits on corporate and regional competitiveness are surely more limited.

It goes without saying that still much work needs to be done, especially in terms of the definition of right performance and connectivity indices and of a more developed theoretical model for measuring network externalities. Once these problems have been overcome, it is more easy to move towards further empirical results testing our conceptual frame of analysis.

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