VU Research Portal

Telecommunications Technologies and Regional Development: Theoretical Considerations and Empirical Evidence

Capello, R.; Nijkamp, P.

published in

The Annals of Regional Science
1996

DOI (link to publisher)

[10.1007/BF01580535](https://doi.org/10.1007/BF01580535)

document version

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Capello, R., & Nijkamp, P. (1996). Telecommunications Technologies and Regional Development: Theoretical Considerations and Empirical Evidence. *The Annals of Regional Science*, 30, 7-30.
<https://doi.org/10.1007/BF01580535>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:

vuresearchportal.ub@vu.nl

Telecommunications technologies and regional development: theoretical considerations and empirical evidence

Roberta Capello¹, Peter Nijkamp²

¹ Department of Economics, Politecnico of Milan, Piazza Leonardo da Vinci 32, I-20133 Milan, Italy

² Department of Economics, Free University, P.O. Box 7161, 1007 MC Amsterdam, The Netherlands

Abstract. The paper provides an analysis of network externalities in the telecommunications sector and their effects on corporate and regional performance. It can essentially be regarded as part of the general theoretical reflection on the role of telecommunications in economic development, by emphasising the importance of telecommunications for future economic growth. However, the advantages derived from these technologies stem not only from the technological changes taking place in the sector, but also from their nature as interrelated technologies. This stems from the fact that when a new subscriber joins the network, the marginal costs of his entry are lower than the marginal benefits he creates for people (firms) already networked. This difference between marginal costs and benefits (in favour of the benefits) inevitably reflects on industrial performance and – via multiplicative effects – on regional performance. The paper presents an empirical part where an effort is made to measure telecommunications network externalities. Regional differences in the exploitation of network externalities emerge between firms located in the north and in the south of Italy.

1. Introduction¹

In the last two decades the role of telecommunications in economic development has intensively been discussed. It is increasingly recognised that telecommunications technologies are the “competitive weapons” upon which the competitiveness of firms and the comparative advantage of regions will critically depend; industri-

¹ The paper is drawn upon the results of a large research project undertaken by the authors. The first author is grateful to Prof. Roberto Camagni of the Politecnico of Milan, who provided financial support for part of the empirical analysis, with funds from the EC and the Italian National Research Council (contract no. 94.00560.CT11). The complete results of the study are published in Capello, 1994. Though the paper is the result of a common research work, Sects. 2, 3 and 4 have been written by R. Capello, while the remaining section has been jointly written.

al, regional and national economic systems which do not adopt such technologies in the near future risk losing their position in the international market.²

The acceptance of the strategic role played by advanced technologies in economic development during the 1980s is witnessed by the European Community's launch of a series of extensive programmes in Research and Technology Development (RACE, ESPRIT, BRITE, STAR, DRIVE, ...) with the aim to decrease regional disparities within the Community. Among these programmes, some are specifically developed with the aim at decreasing regional disparities with the implementation of telecommunications technologies in less favoured regions of the Community (called 'Objective 1' regions), such as the STAR programme.

The importance of these technologies for economic development has stimulated analysis and studies on the adoption and diffusion mechanisms of these technologies. The relatively new branch of industrial economics has generated many interesting studies, emphasising the nature of telecommunications technologies and their intrinsic characteristic to be *interrelated technologies*. Many of these studies have focused their attention on the diffusion mechanisms based on interrelated consumer preferences. In this context, the concept of *network externalities* has been identified, with the aim of explaining the economic rules governing the diffusion mechanisms of these strategic technologies.³

Up to now these two fields of economic theories, viz. *telecommunications as the motor for economic growth on the one hand* and *network externality theory on the other*, seem to be completely separated in the literature. The first field tends to be mainly studied in the framework of regional economic theory: relatively more emphasis is put on the innovation aspect and on the consequences of the economic growth rate of firms and regions, and on the territorial transformation occurring in economic activities when telecommunications technologies are introduced. By stimulating a shrinking of the spatial distance among economic actors, telecommunications technologies may drive the economy towards a completely different spatial structure. In contrast, the second field is much more studied within the context of industrial economic theory, and concerns the analysis of the diffusion mechanisms among firms on the basis of standard economic rules and concepts, such as the "externality" concept.

This paper is an attempt to bring these two fields together, by providing an analysis of network externalities in the telecommunications sector and their effects on corporate and regional performance. It can essentially be regarded as part of the general theoretical reflection on the role of telecommunications in economic development, by emphasising the importance of telecommunications for future economic growth. However, the advantages derived from these technologies stem not only from the technological changes taking place in the sector, but also from their nature as interrelated technologies. This is because when a new subscriber

² The role of telecommunications technologies in the Economy has been largely studied and conceptualised at the Centre of Urban and Regional Development Studies of the University of Newcastle. See, among others, Gillespie et al. 1989; Gillespie and Hepworth 1990; Gillespie and Williams 1988; Goddard et al. 1987; Williams and Taylor 1991.

³ An extensive critical review of the literature on network externality is presented in Capello, 1994.

joins the network, the marginal costs of his entry are lower than the marginal benefits he creates for people (firms) already networked. This difference between marginal costs and benefits (in favour of the benefits) inevitably reflects on industrial performance and – via multiplicative effects – on regional performance.

The present paper develops this concept from both a theoretical and empirical point of view. In particular, Sect. 2 deals with the theoretical aspects, and in particular with the concept of network externality. In Sect. 3 a methodological approach to test network externalities empirically is presented, as well as the empirical results. The empirical analysis is run in both the north and the south of Italy, so that the analysis of the effects of telecommunications technologies is run in two economically contrasting areas. Moreover, firms in the south of Italy have been chosen among those having benefited from the implementation of the STAR programme of the European Community. This programme was run with the aim of decreasing regional disparities through the implementation of advanced telecommunications technologies. Our empirical analysis in the south may be interpreted as an evaluation of the effects that the STAR programme has generated on the economic development of the south of Italy. As we will see, some rather interesting “lessons” can be learnt at policy level, which can be extremely useful for future regional intervention policies aiming at decreasing regional disparities with the help of advanced telecommunications technologies (Sect. 4).

2. Theoretical explanation of the role of telecommunications on regional development

2.1. The nature of telecommunications technologies: the concept of network externality

The term “*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.⁴ 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 on the number of these participants. This basic but crucial statement has strong implications not only for the development trajectories of new networks, but also on some other important elements such as tariff structure, network interconnections, standardisation processes, optimal dimensions of networks and inter-network 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, expressed in terms of its subscriber-base.

Recent studies have highlighted the vital role played by network externalities in understanding the environment required for the adoption of innovations and

⁴ See among others Brosio 1986.

the new capital goods that interlock with them. However, it is still very difficult to give a definition of this concept, as it is subject to many interpretations and easily confused with other phenomena which have little to do with the original concept of external economies. To clarify the concept of network externalities it is useful to keep in mind the two important characteristics attributed to externalities in the economic literature. A first element is *interdependence*, which describes an interaction between the decisions of economic agents. The second is *non-compensation*, so that the one who creates costs (or enjoys benefits) is not obliged to pay for them (Nijkamp 1977).

In the case of network externalities, the first element, interdependence, is easily identified. The decision of a person to join a network is highly dependent on the number of existing subscribers, i.e. on the number of people who have already made the self-same choice.

More complex is the identification of the second characteristic of externalities, i.e. non-compensation. Useful for this purpose is the distinction between the notion of the cost of purchase and that of the adoption of these technologies. In the case of a telecommunications network, the profitability of these technologies depends only to a limited extent on the prices of the equipment on the market (i.e. the price of fax machines, modems, personal computers to link to networks). Much more relevant are the costs of adoption, such as the learning processes and the organisational changes which firms have to cope with in order to use and exploit these technologies. These costs stem from the behaviour of other firms (which technology they adopt) and on the general level of penetration of the technology in the region (Antonelli 1991). The higher the number of adopters, the higher the advantage obtained by the technology. This advantage is not incorporated in the cost of purchase, as this cost is not dependent on the number of already existing subscribers. In this sense, the cost of adopting the technology does not reflect all benefits and advantages generated by that technology, and the "non-compensation" element is present. In other words, the actual economic value of telecommunications networks and services is only partially the benefits that individual consumers derive from telecommunications because (Saunders et al. 1983):

- a) subscribers may value the service by more than the amount that they are required to pay for it, that is, there might be *consumer surplus* that is not quantified;
- b) new telephone subscribers not only incur benefits for themselves, but also increase the benefits of being connected to the system for those who have already joined, that is, there are *subscriber network externalities*;
- c) the willingness to pay a given price to make a telephone call reflects only a minimum estimate of the benefits incurred by the caller and does not reflect the benefits received by the recipient of the call or those whom the caller or recipient of the call then contact, that is, there are *call-related externalities*.

The concept of network externality is then related to the value of the network, which depends on the already existing number of subscribers and differs from the mere cost of purchase of (i.e. access to) the network by that amount of advantage

Fig. 1. Effects of network externalities on market equilibrium

which an individual receives and does not pay for once he joins the network. From this perspective network externalities are the *economic reasons* for the adoption of and entry into the network and are becoming the essential explanation for the diffusion of new interrelated technologies. Firms' decisions to join a new network depend also on the subscriber base of the network and the expectations that potential entrants have of the size of the subscriber base in the near future. Thus, the cost of purchasing the technology itself is not the single element in the decision-making process.

The previous observations can be illustrated by the supply-demand curve in Fig. 1. In this figure, the individual demand curve on the market, labelled "private marginal benefits", represents the benefits that subscribers receive from joining the network. These benefits are fully paid for by the subscribers via the tariff system of a telecommunications network. If the individual private marginal benefit curve 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 represents the social marginal benefits curve, since it is the result of the sum of the individual marginal benefits curve and the externality curve (*Ex*) representing the non-paid for advantages subscribers receive from joining the network.⁵ In this way network externalities are taken into account, thus shifting the equilibrium point from q^* to $q(1)$, which represents the intersection point between social marginal benefits and marginal costs.

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 mar-

⁵ The externality curve is very difficult to construct, as all good "Public Economics" textbooks teach (see for example, Brosio 1986). It is in fact very difficult to evaluate the social benefits with an objective measure. For the purpose of our analysis it is nevertheless very useful to provide a measure, albeit in qualitative terms, of the externality effects on the traditional equilibrium point.

ginal 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 value of the new subscriber's effects on the network.

It is clear that optimal output requires an expansion of market output from q^* to $q(1)$ at which point marginal cost is equal to social marginal benefits. The market equilibrium is in this case "disturbed" by the existence of a positive consumption network externality. The diagram in Fig. 1 is drawn on the basis of an infinite technological capacity of the network, which explains the presence of positive network externalities (i.e. in the chart a positive slope of the externality curve). However, this is not quite realistic. Clearly in the case of fixed networks (i.e. networks with constant technological capacity), *negative consumption network externalities* may arise, as the quality of communications and the rate of failing contacts are affected by congestion (Amiel and Rochet 1987). Moreover, Fig. 1 is constructed under the assumption of a competitive market structure. When this is the case, i.e. when competition exists among telecommunications service providers (such as in the case of the United States), the network externality effects are all internalised by consumers. With respect to a monopolistic market structure (such as in the case of most European countries), the monopolist internalises part of the network externality effects by increasing price and fixing it at a higher value than in the case when network externalities are not present.

2.2. The "network effect" and the "technology effect"

Telecommunications technologies have the intrinsic capacity to impact on the production function of their users by exploiting two different effects:

- the first is related to their capacity to allow adopting firms to introduce innovation processes. As Gillespie and Williams (1988) have widely discussed, the kinds of innovation which may be achieved via the use of telecommunications technologies are different: product innovation, process innovation, managerial innovation, organisational innovation. All these possibilities, once put in place, allow the firm to achieve better economic performance, by decreasing costs or by increasing productivity. These effects are common to all innovation processes when they are inserted in a production function;
- the second effect is typical only of telecommunications technologies, and regards the fact that these are interrelated technologies. In fact, an interdependence between firms' productivity exists when these technologies are used: for telecommunications-networked firms, 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 for advantages obtained by a subscriber joining a network have positive effects on the economic performance of the new subscriber. This holds true also for the already existing subscribers, who obtain non-paid for advantages on their production functions if an additional member uses the network. Thus, if network externalities

have always been represented as one of the (economic) reasons for entering the network, a better economic performance of firms is the (economic) effect they produce on the productivity side.

Network externalities have generally been analysed as consumption externalities, acting on the utility function of an individual and generating interdependent decision-making processes. Our approach in this study is rather a new one, in which we underline that network externalities may also influence the production function, acting as *technical production externalities*. From this perspective, network externalities may be defined as follows. Let:

$$Y_i = Y_i(K_i, L_i, N_{i1})$$

be the production function of firm i , characterised by a certain amount of capital (K), of labour (L), and of a certain volume of information (N). The volume of information (N) is dependent on two variables: on the one hand, it depends on the kind of technology (T_{i1}) which characterises a specific network (network 1) to which the firm i is linked, and on the other on the number of subscribers (S_1) that are linked to network 1. Thus the volume of information for firm i reads as:

$$N_{i1} = N_{i1}(T_{i1}, S_1)$$

where T_{i1} is the technology of network 1 to which firm i is linked and S_1 is the number of subscribers using network 1. The technology (T) is influenced by any (endogenous or exogenous) technological change. There are positive network externalities if:

$$Y_i(K_i, L_i, N_{i1}) > Y_i(K_i, L_i, N'_{i1})$$

where $N'_{i1}(T_{i1}; S_1 + 1) > N_{i1}(T_{i1}; S_1)$

This means, in fact, that the advantages of a greater volume of inputs obtained via the network (dependent on the number of subscribers (or firms) connected to the network), has, *ceteris paribus*, positive effects on the production function of a firm. It is evident that the higher the number of firms using the network, the greater the advantages for firm i .

This definition is useful for another clarification of the concept of production network externalities, as it explains the distinction between the general effects of a technological innovation on the production function and the specific effects of network externalities. At a first glance one could in fact argue that the increase in the productivity of firms can be the result of the adoption of advanced technologies, which allow the achievement of greater efficiency, as would happen in the case of any innovation introduced in a firm. Network externalities generate the same effects as technological innovation, but the *nature* of these effects is entirely different.

Let T_{i1} and T_{i2} be two different technologies, which characterise respectively an old (1) and a new network (2) (e.g. the telex and the teletex networks). Let us assume that every firm is either linked to the old or to the new network, where

the possibility of a transition to a third network is excluded. The volume of information included in the production function may come from the link either with the network characterised by the old technology (N_{i1}), or by the new technology (N_{i2}). In this case network externalities occur if:

$$Y_i(K_i, L_i, N_{i1}) < Y_i(K_i, L_i, N'_{i1})$$

where $N'_{i1}(T_{i1}; S_1 + 1) > N_{i1}(T_{i1}; S_1)$
and if

$$Y_i(K_i, L_i, N_{i2}) < Y_i(K_i, L_i, N'_{i2})$$

where $N'_{i2}(T_{i2}; S_1 + 1) > N_{i2}(T_{i2}; S_1)$.

A firm chooses to switch from the old network characterised by the technology T_1 to the new network, with the technology T_2 , if:

$$Y_i(K_i, L_i, N_{i2}) - Y_i(K_i, L_i, N_{i1}) > 0$$

where $N_{i2}(T_{i2}; S_2 + 1) > N_{i1}(T_{i1}; S_1)$.

This inequality shows that firm i enjoys two effects, the *technology effect*, which represents the increase of productivity generated by the new technology (T_{i2}), and the *network effect*, which determines the difference in the volume of information obtained by a greater number of subscribers linked to the new network ($S_2 + 1$) compared with the lower number of subscribers linked to the old network (S_1).⁶

Our aim in the next sections is to find a way of separating the network effects from the technology effects, so as to be able to measure the network effect, despite the technology effect, at an empirical level.

3. Empirical analysis of production network externalities

This section contains an extremely important issue, since it moves on to the measurement of *production network externalities*. All problems associated with the empirical analysis emerge in this section. In fact, the empirical test of what we argue theoretically is fraught with difficulties. One of the main problems is that, in order to determine the impact of network externalities on corporate and regional performance, it is necessary to have a reliable measuring rod of network externalities, on one side, and corporate and regional performance, on the other. Moreover, production functions are influenced by a large number of elements, which are similar to network externality effects, such as innovation effects and economies of scale effects, and disentangling specific network externality effects from all these other effects is not so simple.

⁶ See Blankart and Knieps (1992) for a similar distinction in the case of consumption network externalities.

The empirical analysis is carried out with a primary database, i.e. small- and medium-sized firms, belonging to different sectors, located in both the north and the south of Italy. For what concerns the south of Italy, interviews have been run among firms which had been involved in the EC programme, called STAR, developed with the aim at decreasing regional disparities with the implementation of advanced and sophisticated telecommunications technologies. In this way, our empirical analysis is able to test to which extent the STAR programme generated positive effects on the performance of firms and of regions. The first part of this section is devoted to the identification of the methodological approach to network externality measurement, while the results of the empirical exercise are set out in subsequent sections.

3.1. *The conceptual and methodological approaches*

Up to now in the present study 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 for 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 other firms connected via the network, but only the highest number of these firms directly or indirectly related to its own business activities. Thus, the decision to join the network is not simply related to the total number of firms already networked, but to the number of specific *business-linked 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 pursued via a telecommunications 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 reason to exist if economic connectivity does not exist*.

Figure 2 is a schematic representation of physical connectivity with the use of graph theory. If, according to this theory, 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 a particular firm, in a static world, is not to be linked to all other possible subscribers, but to achieve full connectivity among only those firms related to its specific business. If we represent such firms in our graph with a bold vertex, and their economic relationships with other firms with bold 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 economic connectivity.

Fig. 2. Undirected graph representing connectivity among firms. *Legend:* ○, Firms; ●, Business-linked firms; —, Possible physical connections among firms; —, Physical and economic connections among specific "business-linked" firms

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 (Fig. 3). Thus, so far we have described a way of measuring network externalities under the assumption of a static world. Hence, Fig. 3 represents a possible way of measuring *network externalities*.

With the use of this method, various important analytical questions remain from a methodological point of view. 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 for the productivity of a firm are the direct relationships with suppliers and customers (Porter 1990). 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.

Fig. 3. Increasing relationship between the degree of connectivity and corporate and regional performance

A *second open question* which arises from the method we have 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 above 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, inevitably has an impact on corporate performance. Thus, any kind of connectivity index has to be adjusted in order to include a measure of the intensity of use. This problem will be taken into account in our empirical analysis. This point is also related to the problem of distinguishing the effects of simple adoption and of intense use of adoption.

The same approach can be applied to the regional level, by identifying a linkage between a connectivity index (measuring the relationships that firms located in that region have with other firms within and outside the region) and a regional performance index. Using the same logic as in the case of the firm level, the connectivity among firms located in that region can be measured with the use of graph theory. A positive derivative between these two indices would explain the existence of network externality effects.

A *third open question* of this method is that *the same weight in terms of economic importance is given to each link* although one can easily anticipate that each first order connection is certainly bound to be of strategic importance for the firm, which could otherwise easily refuse the contact.

The same three limitations, as presented in the open questions above for the firm level, are also true for the regional level; again in this case, only first order relationships are taken into consideration, but the intensity of use of these technologies is missing in this approach. As already discussed above, the first and third open questions are not so crucial, since it can very well be that the most important connections influencing the performance of firms are direct connections and that all of them play a role in the performance of firms. The second open question is the most crucial, since the intensity of use is extremely important for our analysis.

On the basis of the indications obtained by graph theory, a very simple connectivity index may be constructed, representing *the ratio between the number of real connections to the total number of potential connections*.⁷ Although very simple in its formulation, it gives a measure of connection for each firm. The first open question mentioned before querying whether it was the right approach to build a connectivity index only on first order connectivity is not overcome by the way we build our index. However, we may be confident that second and third order connectivity has not the same effect that first order connectivity has on the production function.

The second open question regarding the lack of a measure of intensity of flows is rather important, since it also reflects at an empirical level the extremely important distinctions between the effects that a rare or an intense use of these

⁷ The potential connection of a firm is defined as the total number of existing telecommunication services offered to firms.

technologies has on the production function of firms. We will also run the empirical analysis for a connectivity index weighted with the use of these technologies, thus taking into account their intensity of use. As we will see in the next sections, this index leads to different empirical results.

The third open question concerns the same weight given to all connections, or links. This limitation is not overcome by our connectivity index, although for our analysis it is not a strong limitation.

Despite the relative simple connectivity index used in the empirical analysis, the results obtained are rather satisfactory and provide evidence of the existence of production network externalities. The effects on the regional performance are measured in our empirical analysis as the sum of the positive effects that all firms located in the regions receive. Thus, we postulate that the higher the number of firms enjoying network externalities in a region, the higher the regional performance.

The research methodology followed in order to test the existence of production network externalities is based on a correlation analysis between the connectivity index and the performance index. The analysis contains an initial estimation of the correlation coefficient between the "row" connectivity index,⁸ which measures the simple adoption of these technologies by firms, and the performance index, at the national level. Subsequently, the extent to which the inclusion of the regional dimension leads to better correlation coefficients will be analysed. In this respect, *we may expect stronger regional variations in the results for the two different areas.*

The second step of the empirical analysis is devoted to the introduction of the "frequency of use" variable into our framework. Thus, instead of measuring the correlation between the degree of adoption of these technologies and the performance of firms, the analysis is run between the use of these technologies and the performance of firms.

The second index for the empirical analysis is the performance index. A very simple performance index was chosen, which represents the labour productivity of each firm, defined as the ratio between the turnover of firms in 1991 and the number of employees in the same year. This measure may vary according to specific features of firms, namely:

- the sectors firms belong to. In fact, there may be capital-intensive and labour-intensive sectors;
- the regions where firms are located. It might very well be that a sector is more productive in one region than in another because of the different regional penetration of innovation in capital and the different skill of the labour force.

⁸ In this study "row" connectivity index means the connectivity index constructed taking into account only the adoption data. This index is different from the so-called "weighted" connectivity index which is derived taking into consideration the "frequency of use" of adopted telecommunication services. This index was in fact constructed by multiplying the adoption data with a weight derived by the data on the frequency of use: a weight of 1 was given to services used every day, 0.7 to services used weekly, 0.3 for services used monthly and, finally, 0.1 for services used annually.

To avoid any biased result with the use of our connectivity index, an analysis was undertaken on the database to see whether there was any consistent relationship between some firms' features and their productivity. In particular, an analysis was carried out to see whether the most "labour-intensive" firms belonged to a particular sector, or were located in a specific region; whether the largest firms were located in the same regions and in the same sector. The results of this analysis showed a completely random relationship among these variables. For this reason we have some confidence that the simple performance index measured as the "labour productivity" could be used in our analysis. The next sections are devoted to the empirical results regarding the existence of production network externalities.

3.2. Empirical results

In this section we present empirical evidence for our research issue, i.e. *whether network externalities play a role in the performance of firms and regions*. In particular, in this section the main focus of the analysis is the identification of a possible correlation between the performance index and the connectivity index.

In light of our conceptual framework, we expect to find no correlation between the simple adoption of networks and services and the performance of firms. It is in fact not the simple connection to a network which generates benefits to a firm. It is rather the use of these technologies which creates production network externalities to the networked firms.

In order to test the first hypothesis deduced from our conceptual framework, the simple connectivity index described in the previous section was constructed, i.e. the ratio between the real number of connections to the number of potential connections for each firm of our sample. A very simple performance index has been chosen, representing the productivity of each firm and defined as the ratio between the turnover of firms in 1991 and the number of employees in the same year, as suggested in the previous section.

In order to be sure that the results are not biased by sector or size effects, the analysis has also been run taking into account the sector firms belong to and the size of firms. The "sector" variable has been introduced by running a multivariate correlation between the performance and connectivity indices and the sector firms belong to. The size variable has instead been taken into account by running the multivariate correlation in four different groups of firms with different size, in order to test whether the exploitation of network externalities was related to the dimension of firms. If the size of firms has an impact, we expect an increasing (decreasing) value of the correlation coefficient when the size of firms increases (decreases). This methodology has been applied also at a regional level. Multivariate analysis with sector and size variables allow us to separate out network externality effects from more traditional effects of economies of scale and innovative processes. If there is any relationship between the level of connectivity and the performance of firms and this turns out to be independent from sector or size effects, variations in the performance of firms can be mainly attributed to the existence of (production) network externalities.

A correlation analysis was run on these two indices at both national and regional level (Table 1). The Pearson correlation coefficient R confirms the first impression, having a value of only 0.069. With this value we can go a step further by claiming that almost no correlation exists between these indices. *Our first hypothesis is thus confirmed, since the empirical analysis allows us to conclude that the simple adoption of these technologies as such has no effects on the performance of firms.*

Results do not change when the size and the sectoral variables are introduced in the analysis. The multivariate correlation analysis run introducing the sectoral variable leads to a similar result for the correlation coefficient, which assumes a value of 0.08. When the analysis is repeated in the four groups of firms with different size (in terms of both employment and size), the correlation coefficient changes randomly, and does not demonstrate any relation with the size of the firms.

At the regional level our expectations appear to be verified. The Pearson correlation coefficients change to 0.398 for the north of Italy, and -0.058 for the south of Italy (see Table 1 before). The regional dimension is important in explaining the results of the empirical analysis. The national result is an average value of the two regional analyses, which separately show a different pattern. For the south the correlation is absent, with a value near zero and a negative sign. For the north of Italy, it is undoubtedly true that the situation improves achieving 0.39 as a correlation value and thus showing a weak correlation between the two indices. This result confirms our hypothesis of limited effect of adoption on the performance of firms. Results do not vary in the two regions, when the analysis is run taking into account the sector to which firms belong. In fact, the multivariate correlation analysis shows a similar correlation coefficient value: 0.4 in the north and 0.03 in the south. Moreover, the correlation run separately for the four groups of firms with different size does not show any clear relation between the dimension of firms and the correlation coefficient values.

Table 1. Correlation coefficients between the row connectivity index and the performance index by macro-areas

National results		
	Performance index	Row connectivity index
Performance index	1	0.069
Row connectivity index	0.069	1
Results for the north		
	Performance index	Row connectivity index
Performance index	1	0.398
Row connectivity index	0.398	1
Results for the south		
	Performance index	Row connectivity index
Performance index	1	-0.0588
Row connectivity index	-0.0588	1

If we adjust the connectivity index to the frequency of use of these services, the results of the correlation analysis at the *national level* of Italy show a Pearson correlation coefficient R still very low, viz. 0.11 (Table 2). At the regional level, it appears immediately that there is a better fit for a linear correlation in the case of the north than for the south. This impression is confirmed by large differences in the Pearson correlation coefficients, whose value varies from 0.085 for the south to 0.473 for the north (see Table 2). These results show that:

- the regional variation in correlation analyses is even greater in the case of the correlation between the simple adoption and the firms performance. The national correlation value is nevertheless still very low, because it averages an even lower R in the case of the south and a higher value for the north;
- as expected, the most developed regions are also the ones which gain more from network externality effects, while backward regions are not yet able to achieve economic advantage from their adoption;
- the use of these technologies is strategic for the exploitation of production network externalities. In northern Italy, where these technologies are used more frequently, the economic advantages from their adoption is certainly higher than in southern Italy.

3.3. Conditions to exploit production network externalities

Some doubts remain on the previous analysis. The first is to “reveal the inner working of” the linkage between the connectivity and the performance index identified before, by defining the variables and the elements which characterise the relationship between the two indices of connectivity and performance. The analysis run in the previous section does not tell us *why and under which conditions the correlation takes place*. The second doubt is that at present the results show the existence of a correlation between the two indices, without showing the *direction of causality*. We have interpreted the results as the higher the connecti-

Table 2. Correlation between the weighted connectivity index and the performance index by macro-areas

National results		
	Performance index	Weighted connectivity index
Performance index	1	0.11
Weighted connectivity index	0.11	1
Results for the north		
	Performance index	Weighted connectivity index
Performance index	1	0.473
Weighted connectivity index	0.473	1
Results for the south		
	Performance index	Weighted connectivity index
Performance index	1	0.0856
Weighted connectivity index	0.0856	1

ty, the greater the performance, but this statement could easily be expressed in the reverse, by claiming that the greater the performance, the greater the connectivity.

On the basis of a path analysis to be run in this section, these ambiguities are overcome, by imposing and testing a clear causal path, starting from greater connectivity to better performance. On the basis of our conceptual approach, some *conditions* may be foreseen, which develop to avoid bottlenecks and barriers to the exploitation of production network externalities, on both the supply and demand side. Figure 4 summarises our conceptual model for production network externalities. The upper part of the chart represents the conditions on the demand side in order to exploit better production network externalities, while the lower part summarises the conditions on the supply side. When these conditions are present, we expect firms to be able to exploit the advantages from these technologies.

Our intention in this section is to explain the relationship between the connectivity index and the performance index. Other variables may have been taken into account, such as the size of the firms of the sector they belong to, which may have a direct or an indirect effect on either the performance or the connectivity index. However, we restricted our analysis to some specific variables (presented below) for a number of reasons:

- a) from the theoretical point of view, the variables used in our model represent the most common variables mentioned in the literature on telecommunications

Fig. 4. A general model for network externality exploitation estimates

diffusion processes as those variables having strong influence on the decision to adopt these new technologies;

- b) again from a theoretical point of view, there is no reason why larger firms should have different contact patterns than small firms, as is also witnessed by the results obtained before, where the size variable was insignificant with respect to the estimation of network externalities. Larger firms may be more able to accept innovation, as is well known in theory, and this aspect is indirectly taken into account in one of the included variables in our model, namely the variable reflecting the innovative behaviour of a firm;
- c) from a statistical point of view, a model with too many explanatory variables has low explanatory power. Thus, only the variables quoted in the literature as the most important variables explaining adoption processes were introduced in the model. Moreover, the good results achieved in the empirical analysis suggest that no important explanatory variable is missing.

The methodology used is the estimation of path analysis models, which have an important characteristic: relations between variables must have an evident causal direction and this allows us to disentangle the linkage between the connectivity and the performance index. As we mentioned already, the intermediate variables explain the conditions under which the correlation between the connectivity and the performance index takes place. In particular, their presence guarantees that the adoption of new technologies generates better corporate performance. To be sure that the direction of causality between the performance and the connectivity index was the most appropriate one, we estimated the causal path analysis model also by imposing the reverse direction of causality that the one presented in Fig. 4, i.e. a model where greater performance was the independent variable which explains greater connectivity. The poor results obtained have demonstrated once more that our hypothesis was the right one.

Concerning the supply side, at least three conditions have to be present in order to allow firms to exploit production network externalities:

- a) the *achievement of a critical mass of adopters*, especially for interrelated services, e.g. electronic mail. The user value of these technologies is in fact related to the number of already existing subscribers. Our idea, tested in another study (Capello 1994), is that the number of already existing subscribers is one of the most important reasons for joining networks and services. The existence of at least a certain level of subscribers is a necessary condition to stimulate a *cumulative self-sustained mechanism*. If a critical mass is not achieved, the risk is that potential adopters are not sufficiently stimulated to adopt these technologies. In other words, the adoption process of these technologies has to be strongly supported by the supply until a critical mass is achieved;
- b) another important factor is *constant assistance* in the first phases of development from the supply side, in terms of the technical, managerial and organisation support necessary for an innovative exploitation of these technologies. This process requires a strong organisational effort by the subscriber, who most of the time needs organisational support from people with expertise and experience. The STAR programme itself has certainly taken this aspect into ac-

count. Some specific measures were devoted to the implementation of "demonstration and promotion actions", through specialised centres whose task was to develop a "telematics culture" among potential users. However, in some countries such as Italy, these centres have put the emphasis of their work more on *technical* rather than *organisational aspects*. Centres in fact promoted these services, by mainly concentrating on their technical capacities, but while they assured technical support to users, they did not provide adequate information and advice about organisational problems and changes which have to be coped with in order to exploit production network externalities. We expect therefore that the lack of organisational support will act as a bottleneck in the exploitation of network externalities;

- c) another crucial factor for the exploitation of production network externalities is the *clear identification of the way these technologies may be useful for business purposes*. As we explained before from a conceptual point of view, these technologies are multi-faceted complex technologies and require a certain degree of organisational changes in order to become useful to business needs. For these reasons, the supply side has to demonstrate the importance of these technologies for business needs, in order to stimulate an interest on the demand side.

Although there is a set of critical success conditions required on the supply side, it has to be added that also on the demand side there are some necessary requirements in order to exploit production network externalities:

- d) to begin with, as a consequence of what has been said about the complexity of these technologies, the capacity of firms to accept new technologies and to exploit them is a very important consideration. We expect that firms have to be highly *flexible with regard to organisational changes* if they want to exploit production network externalities. The better the capacity of adapting the organisational structure to external changes, the greater the probability of exploiting production network externalities;
- e) another factor which greatly assists firms to exploit production network externalities is their *innovative behaviour* or their level of entrepreneurship, this business acumen guarantees the achievement of competitive advantage through these technologies. In fact, via learning processes and previous experience of innovation, the firm may have acquired the necessary organisational and managerial know-how to be able to implement organisational changes required to achieve competitive advantage. The higher the number of innovations already adopted by the firm, the greater the probability of exploiting production network externalities.

To be sure that the direction of causality between the performance and the connectivity index was the most appropriate one, we estimated the causal path analysis model also by imposing the reverse direction of causality that the one presented in Fig. 4, i.e. a model where greater performance was the independent variable which explains greater connectivity. The poor results obtained have demonstrated once more that our hypothesis was the right one.

For the north of Italy, the results obtained are satisfactory. Figure 5 shows both the values of the estimated parameters and the T -student test results for the estimated parameters (presented in brackets). In interpreting the results of both the north and the south of Italy, it should be kept in mind that all variables have been standardised with unit variance and mean zero, in order to be able to compare the relevance of individual parameters. Some conclusions can already be drawn:

- almost all parameters are statistically significant, having T -student values over 2;
- all estimated relations have the expected sign;
- the model itself fits very well with the given variables (P -value = 0.01).

Our conceptual model thus appears to be confirmed: *micro-conditions allowing firms to exploit network externalities are present in northern Italy.*

A different result is indeed achieved for the south of Italy. As Fig. 6 shows, the results of the same conceptual model are quite different and in actual fact are less satisfactory, as expected. At first glance one can immediately make a general remark that the model does not fit with the empirical estimations. Most estimated parameters, apart from two of them, are not statistically significant, showing T -student values below the critical value of 2.

Fig. 5. Estimated path analysis model for the north of Italy

Fig. 6. Estimated path analysis model for the south of Italy

In any other circumstances this result would have been interpreted as a negative result, destroying from an empirical point of view the conceptual framework underpinning these results. On the contrary, in our case these results support our expectations: *micro-conditions to exploit production network externalities seem not to be present in southern Italy*. We can even argue that with this analysis we have been able to identify the barriers and bottlenecks existing in the exploitation of production network externalities and which hinder the achievement of better economic and spatial performance via the use of advanced telecommunications technologies.

4. Conclusions and policy implications

The empirical analysis run in this study contains some *policy implications* regarding the effects these technologies have in reducing inter-regional disparities. In particular, a first crucial result is that mere accessibility to advanced telecommunications infrastructures and services does not necessarily lead to a better corporate and regional performance. The results in the south of Italy are representative in this respect, since the empirical analysis shows no correlation between greater intense use of these technologies and better industrial and regional performance. From such results, one may be inclined to draw a negative conclusion about the effects that the STAR intervention programme run by the EC has

generated on the performance of local firms. However, such a conclusion is far too pessimistic and could be highly criticised, since:

- a) evaluations of regional impact require a long-term perspective. Regional effects take place in the long-run, and only a long-term evaluation can really test the benefits of the programme. Our analysis took place only a few months after the end of the programme, when all the spin-off and spillover effects at regional level may still not have generated all their effects;
- b) in the short run, an evaluator can only be concerned with the *potential* that these technologies have to influence regional performance. In this respect, this study is useful, since it emphasises *bottlenecks* and *barriers* which hamper the exploitation of production network externalities by firms. The conditions put forward by our conceptual framework and tested in our empirical analysis in order to overcome these bottlenecks and barriers suggest some policy recommendations. These recommendations should be taken into consideration when developing an infrastructure intervention policy, like STAR, which aims to decrease regional disparities.

The first crucial precondition to assure a sustainable adoption of these technologies (and thus greater real connectivity) is the achievement of a *critical mass* of adopters especially for interrelated services, such as electronic mail. The user value of these technologies is in fact related to the number of already existing subscribers, since the attraction for a new potential subscriber to join the network is the possibility of being linked to a great number of subscribers. The existence of a certain number of subscribers is a necessary condition to stimulate a *cumulative self-sustained mechanism*. The number of subscribers at which this self-sustained mechanism takes place varies according to the sector to which firms belong. Some sectors are more inclined to accept the risk of a low number of subscribers, since telecommunications technologies are in any case extremely important for their business, as it was also pointed out in our empirical analysis. A policy recommendation underlining the importance of a number of subscribers may appear rather too general, since the critical mass level is extremely difficult to be measured at an empirical level (see also Allen 1988). However, it is our opinion that the general suggestion on the importance of the number of subscribers in a network has to be stressed in telecommunications development policy guidelines, since many programmes on telecommunications implementation (at both European and national levels) have demonstrated to underestimate a so strategic development tool, probably because of the high level of financial investments required to exploit it.

Another critical factor for the achievement of a great number of adoptions is the *clear identification of the way these technologies may be useful for business purposes*. These technologies are by no means simple technologies and require a certain degree of organisational changes in order to become useful to business needs. This process requires a strong organisational effort on the part of the subscriber, who most of the time needs organisational support from specialised telecommunications experts. The STAR programme has indeed taken this aspect into account. Some measures were devoted to the implementation of "demonstra-

tion and promotion actions", through specialised centres whose task was to develop a "telematic culture" among potential users (the so-called 4.2 measures). However, as the results underline, the crucial element in this process is not only the "technical aspect", but rather the "*organisational aspect*", because of the complexity of integrating these technologies within the established business structure. From the results obtained, it seems that these centres promoted these services underlining in most cases their technical capacities, and assuring technical support to firms. They did not, however, deal sufficiently well with organisational problems and changes which have to be borne in order to exploit these technologies in the best way.

The economic environment of the south, as is generally the case in less developed regions, is weak in terms of traditional crucial factors which stimulate the adoption of technological change. In fact, in the south the economic environment is characterised by: a) a very high risk aversion by potential adopters, b) very limited competitive market forces, c) a stable division of market shares. All these features define a very difficult environment where self-sustained adoption mechanisms of new technologies risk finding no stable ground in the short term and where for these reasons the usual incentive policies have to be extremely strong especially in the first phases of the diffusion processes. The STAR programme heavily subsidised networks and services during these early years (to the extent that these technologies were free of charge for the pioneering users). This incentive policy has turned out to be extremely useful. However, there has been no adequate policy underlining the potentialities of these technologies in terms of business needs solutions or even in terms of new market niches to be exploited. The provision of these complex technologies has to cover especially the *organisational aspects*, rather than the simple technical details. Moreover, a successful provision requires the identification of the ways in which these technologies can be exploited to solve *business needs* or to achieve new *business goals*. The organisational aspect and the business idea aspect have not been regarded as strategic factors for adoption; neglect of these two aspects could create serious bottlenecks in the adoption process and hamper the exploitation of network externalities by firms and, via multiplicative effects, by regions.

All these remarks lead to the identification of some *policy guidelines* for future intervention policies which have to be taken into account to achieve successful results.

First of all, from all that has been said above, it is possible to claim that the promotion policies of these technologies have to be based on a *bridging mechanism between demand and supply*, i.e. they have to be able to link business needs, or even potential business needs, to the existing technological potentialities. Suppliers should be able to provide not only the physical infrastructure and technical support, but also provide the business angle on how to exploit these technologies, on the basis of business needs of potential users. One way of dealing with this problem is to customise these networks and services as much as possible to the personal needs of potential users.

A second lesson from the STAR programme is more related to the "spatial circumstances" in which these technologies have to be promoted. A crucial resource for the development of these technologies is *entrepreneurship*. In other words, the

presence of risk aversion and of non-competitive market structures discourages adoption processes of these technologies, since no market force exists under those conditions which can stimulate firms to bear the organisational, managerial and financial costs necessary for a successful adoption. Thus, local entrepreneurship turns out to be a strategic element for successful adoptions. If this is the case, innovative policies have to take this aspect into consideration, choosing, among other factors, local areas where *entrepreneurial capabilities* are available. Thus, instead of supplying these technologies to all areas in less developed regions, as has been the case with the STAR programme in Italy, innovative policies should rather be focused on the most dynamic areas in terms of both technical and entrepreneurial capabilities. These areas, these "*local milieux*", represent the most efficient and dynamic areas, where a technological policy could lead in the long run to good results in terms of network externality exploitation. This modern view of intervention policies suggests that technology policy, when implemented without a territorial perspective, either results in a cumulative process of spatial concentration of technological development, or lazily remains inefficient, as it overlooks the adoption problems of small- and medium-sized enterprises.

Another important aspect in the technology policy for regional development is its capacity to overcome *local economic constraints*. Telecommunications technologies are seen by the users as a way to achieve information and know-how which are not present locally, and especially which are typical of advanced economic areas. For this reason, the STAR programme is seen as crucial for shrinking the (physical and economic) distance between backward and more advanced areas in the Community. However, the way in which the programme has been run and managed, guaranteeing an advanced link in backward areas, has lost part of its attractiveness. The creation of *a club of poor regions* does not seem to be the right policy guideline for ensuring local sustainable economic development. In the Italian case, the implementation of advanced networks and services in the south, with no direct link to the north of Italy, has acted as a disincentive for adoption.

The impact of STAR on regional development is geared to overcoming these bottlenecks and barriers which hamper the full exploitation of these technologies. The capacities of future intervention policies aiming to solve these problems will determine the extent to which the implementation of these technologies will influence regional performance in the future. For this reason, it is of vital importance to assure continuity in the provision of these technologies, via the launch of a second intervention programme. This would have two aims: a) to overcome the present bottlenecks and barriers in the adoption processes, taking into account the "lessons" learnt by the first phase of the programme, b) to achieve the expected positive effects on the regional performance, at present hampered by both the low level of adoption and of use.

References

- Allen D (1988) New Telecommunications Services: Network Externalities and Critical Mass. Telecommunications Policy, September, pp 257–271

- Allen D (1990) Break-up of the American Telephone Company: the Intellectual Conflict Before and Since, paper presented at the 8th International Conference of the International Telecommunications Society, on "Telecommunications and the Challenge of Innovation and Global Competition", held in Venice, 18–21 March
- Amiel M, Rochet J (1987) Concurrence entre Réseaux de Télécommunications: les Conséquences des Externalités Négatives. *Ann Télécomm* 42 (11/12):642–649
- Antonelli C (1991) The International Diffusion of Advanced Telecommunications: Opportunities for Developing Countries. OECD Publication
- Blankart C, Knieps G (1992) The Critical Mass Problem in a Dynamic World: Theory and Applications to Telecommunication. In: Klaver F, Slaa P (eds) *Telecommunications: New Signposts to Old Roads*. IOS Press, Amsterdam, pp 55–63
- Bradley S, Hausman J (eds) (1989) *Future Competition in Telecommunications*. Harvard Business School Press
- Brock G (1981) *The Telecommunications Industry: The Dynamic of Market Structure*. Cambridge, Harvard University Press
- Brosio G (1986) *Economia e Finanza Pubblica*. La Nuova Italia Scientifica, Rome
- Camagni R, Capello R (1989) Scenari di Sviluppo della Domanda di Sistemi di Telecomunicazione in Italia. *Fin Mark Prod* 1:87–138
- Capello R (1991) L'assetto Istituzionale nel Settore delle Telecomunicazioni. In: Camagni R (ed) *Computer Networks: Mercati e Prospettive delle Tecnologie di Telecomunicazione*. Etas Libri, Milan, pp 163–260
- Capello R (1994) *Spatial Economic Analysis of Telecommunications Network Externalities*. Avebury, Aldershot
- Crandall R, Flamm K (eds) (1989) *Changing the Rules: Technological Change, International Competition and Regulation in Communications*. The Brooking Institution
- Curien N, Gensollen M (1987) A Functional Analysis of the Network: a Prerequisite for Deregulating the Telecommunications Industry. *Ann Télécomm* 42 (11/12):629–641
- Foreman-Peck J, Mueller J (1988) *The Spectrum of Alternatives of Market Configurations in European Telecommunications*. research study, Berlin-Newcastle, April
- Gillespie A, Hepworth M (1986) *Telecommunications and Regional Development in the Information Economy*, Newcastle Studies of the Information Economy, CURDS, Newcastle University, no. 1, October
- Gillespie A, Williams H (1988) Telecommunications and the Reconstruction of Regional Comparative Advantage. *Environ Plan A* 20:1311–1321
- Gillespie A, Goddard J, Hepworth M, Williams H (1989) Information and Communications Technology and Regional Development: an Information Economy Perspective. *Sci Technol Ind Rev* 5:86–111
- Goddard J, Charles D, Howells J, Thwaites A (1987) *Research and Technological Development in the Less Favoured Regions of the Community – STRIDE*. Commission of the European Communities, Document, Luxemburg
- Mueller J (1991) The European International Market for Telecommunications. *Eur Econ Rev* 496–503
- Nijkamp P (1977) *Theory and Application of Environmental Economics*. North-Holland, Amsterdam
- Philip G (1990) The Deregulation of Telecommunications in the EC. *Int J Inf Manag* 1:67–75
- Phillips A (1990) Changing Markets and Institutional Inertia: a Review of US International Telecommunications Society on "Telecommunications and the Challenge of Innovation and Global Competition", held in Venice, 18–21 March
- Porter M (1990) *Competitive Advantage of Nations*. McMillan, London
- Saunders R, Warford J, Wellenius B (1983) *Telecommunications and Economic Development*. The Johns Hopkins University Press, London
- Von Weizsaecker CC, Wieland B (1988) Current Telecommunications Policy in West Germany. *Oxf Rev Econ Policy* 4(2):20–39
- Williams H, Taylor J (1991) ICTs and the Management of Territory. In: Brotchie J, Batty M, Hall P, Newton P (eds) *Cities of the 21st Century*. Halstead Press, Longman, Cheshire, pp 293–306