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Keskusteluaiheita – Discussion papers

No. 724

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REGULATORS AND COMPETITION SPURRING OR RETARDING INNOVATION IN THE TELECOMMUNICATIONS SECTOR?

ISSN 0781-6847 03.08.2000

KOSKI, Heli, **REGULATORS AND COMPETITION SPURRING OR RETARDING INNOVATION IN THE TELECOMMUNICATIONS SECTOR?** Helsinki: ETLA, Elinkeinoelämän Tutkimuslaitos, The Research Institute of the Finnish Economy, 2000, 21 p. (Keskusteluaiheita, Discussion Papers, ISSN 0781-6847; No. 724).

ABSTRACT: This paper empirically explores how technology policy affects innovation behaviour in the telecommunications sector. Our empirical analysis aims at shedding light on the following highly topical issues: (I) Whether opening up the domestic market to competition spurs innovative activity?, (ii) Whether the presence of independent regulatory agency influence innovation behaviour of telecommunications operators?, and (iii) What is the direction of Granger-causality between innovation creation and technology diffusion in the communications sector? We develop an econometric model that takes into account the dynamic, non-linear nature of the innovation process and interdependency between equations for a patent count variable, R&D and technology diffusion. We use data from 61 major telecommunications operators between the years 1991 and 1996 to investigate how technology policy has influenced their innovative activities, i.e. their R&D expenditures and the number of patent applications, and the diffusion of communications technologies in their domestic markets.

KEY WORDS: Innovation, technology diffusion, telecommunications, technology policy

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TIIVISTELMÄ: Tutkimus selvittää aineistoanalyysin avulla teknologiapolitiikan vaikutuksia innovaatiokäyttäytymiseen telekommunikaatiosektorilla. Empiirisen analyysin tavoitteena on valaista seuraavia ajankohtaisia kysymyksiä: (I) Kannustaako kotimaisten markkinoiden avaaminen kilpailulle innovaatiotoimintaa?, (ii) Onko riippumattoman sääntelyviranomaisen läsnäololla vaikutusta teleoperaattoreiden innovaatiokäyttäytymiseen?, (iii) Mikä on Granger-kausaalisuuden suunta innovaatioiden kehittämisen ja teknologioiden leviämisen välillä viestintäsektorilla? Tutkimuksessa kehitetään ekonometrinen malli, joka ottaa huomioon innovaatioprosessin dynaamisen, epälineaarisen luonteen sekä keskinäisen riippuvuuden yritysten patentointia, T&K-menoja ja teknologioiden leviämistä kuvaavien yhtälöiden välillä. Raportoidussa empiirisessä tutkimuksessa analysoidaan teknologiapolitiikan vaikutuksia teleyritysten innovaatiotoimintaan - niiden T&K-menoihin ja patenttihakemusten lukumäärään, sekä viestintäteknologioiden leviämiseen yritysten kotimaan markkinoilla - käyttäen aineistoa 61 suuren teleoperaattorin toiminnasta ajanjaksona 1991-1996.

AVAINSANAT: Innovaatio, teknologioiden leviäminen, televiestintä, teknologiapolitiikka

1. INTRODUCTION

Patent right issues have played an important role in the telephone industry from its very beginning[1]. The importance of patents, or technical advancements (e.g. digitisation and further innovations related to it) as a strategic means to achieve competitive advantage, is increasing as international competition in the communications sector intensifies. Also, it seems likely that a global trend of privatisation of telecommunications operators during the 1990s has increased the importance of patents as private companies are more likely to treat their patents as a source of profit (rather than as public property) than publicly owned companies do. Not only technological innovations but also patent right royalties or license fees related to them may provide telecommunications operators with a non-negligible source of income.[2] Telecommunications operators may also find it increasingly costly *not to innovate* since "*the license fees for patents relating to communications products...are becoming a major cost for communications product manufacturers and their customers, including the communications service providers* (Krechmer, 1997)".

Telecommunications operators are key players in the communications sector but - to my best knowledge - the literature does not provide any systematic empirical analysis on their innovation behaviour. This paper addresses the following highly topical issues: (I) Whether opening up the domestic market to competition spurs innovative activity?, (ii) Whether the presence of independent regulatory agency influence innovation behaviour of telecommunications operators?, and (iii) What is the direction of Granger-causality between innovation creation and technology diffusion in the communications sector? This paper will empirically investigate these questions by using data from the patenting and R&D activities of a sample of the world's major telecommunications operators. It will provide an econometric model of the system of equations that capture complex relationships between entrepreneurial innovation (i.e. the patent-R&D relationship) and network evolution.

Previous empirical studies investigating the patterns of entrepreneurial innovation behaviour have primarily used one of the following two approaches. One stream of literature has treated R&D expenditures as endogenous and explored factors affecting its determination (see, e.g., Lichtenberg, 1987; Menezes-Filho et al., 1998). The other stream of literature has focused on the relationship between patents and R&D expenditures: variation in the number of a firm's patent applications is typically modelled as a function of its current and previous R&D expenditures (see, e.g., Hausman et al., 1984; Lieberman, 1986). This literature treats firms' R&D expenditures as exogenous with the exception of few recent studies (see Blundell et al., 1995, 1997; Montalvo, 1997) that point out that patents may also induce future R&D and that therefore R&D expenditures should be treated as *weakly exogenous*. Since the order of magnitude of money allocated to R&D can be regarded as one of the strategic decision factors of a

1 The validity of the patent right of Alexander Bell for a telephone - his patent application was filed only a few hours earlier than the one of Elisha Gray - was challenged various times after its allowance in 1876.

2 Hong Kong Telecom provides a good example of this. It announced in its annual report of the financial year 1995/96 that it had developed a new technology, an intelligent underlay/overlay technology for cellular networks. Hong Kong Telecom patented this technology, and by March 1997, license fees had generated HK$2.3 million (Espicom database: Communications Companies Analysis).

firm, our econometric model of the patent-R&D relationship, unlike the previous ones, treats firms' R&D expenditures as an endogenous variable.

Our study will also address the question of sample selection (bias) in the determination of the number of patent applications a firm files. It seems likely that in many cases the patent count variable is correlated with the selection mechanism that defines whether or not a firm decides to patent its innovations.[3] Some recent studies have applied the sample selection model to the count data model (see, e.g., Greene (1997b) for such modelling and further discussion on the topic). Unlike previous studies, we will extend our application to estimate the system of interdependent equations for the (truncated) count data variable, sample selection mechanism, endogenous R&D and the diffusion of innovations.

Our econometric model takes into account potential contemporaneous interdependency between technology creation and diffusion, and the impact of network externalities on entrepreneurial innovation.[4] It also investigates direction of Granger-causality or feedback effects between the dependent variables of our interest.[5] This provides a contribution to previous empirical studies on the diffusion of network technologies (see, e.g., Economies and Himmelberg, 1995; Majumdar and Venkataraman, 1997; Koski, 1999a) and also on the broader stream of literature on the diffusion of innovations (see, e.g., Stoneman, 1995). These previous empirical explorations typically deal with innovation diffusion and creation separately whereas we econometrically model and empirically analyse joint determination of these processes.

Few previous empirical studies have analyzed directions of causality in technical change: Lach and Schankerman (1989) and Toivanen and Stoneman (1998) investigate the dynamic relationship between entrepreneurial investments and R&D expenditures. The former study finds that R&D Granger-causes investment but not vice versa, whereas the empirical estimation results of the latter study suggest that causality is unidirectional from investment to R&D. Our study contributes to the economic literature on technological change by exploring the presence of Granger-causality between innovation creation and technology diffusion.

We use firm-level data from 61 of the world's major telecommunications operators between the years 1991 and 1996 in our empirically investigation. Our data suggest that opening up telecommunications markets for competition has had a clear positive impact both on innovation creation and diffusion in the telecommunications sector. Moreover, the type of regulatory agency seems to influence both innovation creation and diffusion in national communications markets. Furthermore, the results of our empirical exploration suggest that the diffusion of new technologies may have substantial implications for innovation creation on network markets. We do not, however,

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3 For instance, the number of patent applications may be related to a firm's strategic decision whether or not it prefers secrecy to patenting.

4 In the presence of network externalities, demand is strongly affected by major diffusion processes (see, e.g., David, 1985; Arthur, 1989; Antonelli, 1992; Economides, 1996). See Koski (1999b) for an industry-level investigation of the determination of the R&D intensity of the communications sectors among OECD countries.

5 We employ Granger's (1969) definition of causality in exploring the causal patterns between network evolution and entrepreneurial innovation: variable X causes variable Y if taking into account the value of variable X at time t-1 leads to improved prediction for variable Y at time t. When causality is not unidirectional from variable X to variable Y, or the hypothesis that variable Y causes variable X cannot be rejected, the relationship between the variables is characterised by feedback.

find any feedback effect from R&D to the diffusion of network technologies. In other words, the link between innovation creation and diffusion seems unidirectional: network externalities related to the demand for network technologies induce innovation on the supply side of network markets.

This paper is organised as follows. Section 2 gradually builds an econometric model for innovation behaviour and evolution of new technologies in network markets. Section 3 introduces data used in our empirical investigation. Section 4 discusses the empirical findings of the estimated econometric model. Section 5 concludes with a brief discussion on policy implications of the results of our empirical exploration.

2. ECONOMETRIC MODELLING OF INNOVATION DYNAMICS IN NETWORK MARKETS

This section will develop an econometric model that takes into account the dynamic, non-linear nature of the innovation process and contemporaneous and inter-temporal interdependency between technology creation and its diffusion. Our model is used for empirically investigating the direction of causality and the presence of feedback mechanisms between network evolution and entrepreneurial innovation. We measure the order of magnitude of a firm's innovative activity by two endogenously determined variables, the number of patent applications filed and the R&D expenditures. We consider the evolution of two major communications technologies, fixed and mobile telecommunications technologies. We use a heterogeneity term to take into account unobservable factors that may influence innovation creation and diffusion in network markets.

(I) Patent-RD relationship

We will first discuss the part of our econometric model that investigates the relationship between the number of patent applications filed and the R&D expenditures. The variance of the number of patent applications is notably higher than its mean suggesting the presence of over-dispersion. This indicates that the Poisson model - that forces the conditional mean and variance of the dependent variable to be equal - is insufficient to describe our data.

Another notable characteristic of our database is that 60 % of the sampled firms have not filed patent applications in the United States. Consequently, our data comprise a substantial number of zero outcomes for the number of patents applied. Since 79 % of the sampled firms are non-US telecommunications operators, it seems possible that the zero values of our sample are related to the cross-country differences in the direction and strength of external patenting (see Sassu and Paci, 1998).[6] Firms' strategic decisions defining whether or not they file patent applications in the US (or abroad in general) - depending possibly on both firm- and country-specific factors

[6] The previous literature suggests two potential reasons for excessive zeros among patent count data: non-linear nature of innovation process and relatively large number of firms preferring secrecy to the patenting (Crepon and Duguet, 1997).

such as competition policy in the telecommunications sector of the country of origin of a company - may play a critical role here. This means that sample selection bias may occur or that unobserved heterogeneity related to the number of patent applications filed may be correlated with the unobserved heterogeneity term in the sample selection mechanism.

To take into account both the presence of over-dispersion and potential sample selection bias we proceed as follows. We re-specify the Poisson model with log-normal heterogeneity[7] and determine the conditional probability distribution for y_{it}, the number of patent applications filed, as follows:

$$P(y_{it} \mid X_{1it}, \varepsilon_i) = \exp[-\lambda_{it}(\varepsilon_{it})]\lambda_{it}(\varepsilon_i)^{y_{it}} / y_{it}\,!, \tag{1}$$

where $\lambda_{it}(\varepsilon_i) = \beta_1^{'} X_{1it} + \varepsilon_i$, and the vector of explanatory variables, X_{1it}, comprises a firm's R&D expenditures and other observable characteristics. Unobserved heterogeneity, ε_i, is an iid random variable that is assumed to remain constant over time and have zero mean and variance σ_1^2. We allow ε_i to be correlated with the error terms of the sample selection mechanism and the R&D equation. We assume that the number of patent applications filed by a firm (y_{it}), whether or not it files patent applications in the United States (z_{it}, a dummy variable that gets a value of 1 if a firm files patent applications in the US and 0 otherwise) and its R&D expenditures (RD_{it}) are independent conditioned on ε_i.

In addition, our analysis is slightly complicated by the fact that our data includes a few companies that have filed a relatively high number of patent applications during the sampled time period. Since the majority, almost 90 % of the annual patent application observations, gets a value lower than 10 – i.e. represents typical count data – but there are nevertheless a few exceptionally high values, we truncate the patent variable.[8] Truncation in the case of the Poisson model can be undertaken by using the laws of probability to modify the density function (see, e.g., Grogger and Carson, 1991; Greene, 1997a). In other words, the Poisson model is derived by dividing the truncated probability function by the probability function of the dependent variable being at or above the truncation limit. The truncated Poisson model can then be written as follows:

$$P(y_{it} \mid X_{1it}, \varepsilon_i) = \frac{\exp[-\lambda_{it}(\varepsilon_{it})]\lambda_{it}(\varepsilon_i)^{y_{it}} / y_{it}!}{1 - \exp[-\lambda_{it}(\varepsilon_{it})]\lambda_{it}(\varepsilon_i)^{y_k} / y_k!}, \tag{2}$$

where y_k is the truncation value for y. We use the probit model for explaining a firm's decision whether or not to file a patent application in the US. The conditional probability to file patent applications in the United States can be determined - as the conditional distribution of u_{2it}, the error term of the equation for the sample selection

[7] See, e.g., Greene (1997b) and Crepon and Duguet (1997) for a similar approach.

[8] This is also necessary because the statistical programs are not able to calculate the Gamma function -which is needed to estimate the Poisson model - for high values. Here the dependent variable is truncated to have values at or below 20.

mechanism is by joint normality of ε_i and u_{2it}: $f(u_{2it}|\varepsilon_i) = N[(\rho_1/\sigma_1)\varepsilon_i,(1-\rho_1^2)]$ - as follows:

$$\Pr(z_{it} = 1|X_{2it},\varepsilon_i) = \Phi(\frac{1}{\sqrt{1-\rho_1^2}}(\beta_2^{'}X_{2it} + (\rho_1/\sigma_1)\varepsilon_i)), \tag{3a}$$

where X_{2it} is a vector of observable characteristics (see Section 3 for their description). The conditional probability that a firm chooses *not* to file patent applications in the United States is therefore:

$$\Pr(z_{it} = 0|X_{2it},\varepsilon_i) = 1-\Phi(\frac{1}{\sqrt{1-\rho_1^2}}(\beta_2^{'}X_{2it} + (\rho_1/\sigma_1)\varepsilon_i)). \tag{3b}$$

We will next consider (endogenous) determination of a firm's R&D expenditures. In the presence of network externalities, not only the sales level matters but also the expected network size may influence a firm's R&D expenditures (see Koski, 1999b). This may happen, since the number of network users affects both a network supplier's demand and supply. Therefore - as the equilibrium R&D level is determined via the price mechanism[9] - the installed user base of network technology may influence the R&D expenditures. Two communications technologies are particularly important in the telecommunications sector: the fixed and cellular telecommunications technologies. We assume that the R&D expenditures depend on the expected network size of these technologies, other observable characteristics of the sampled firms (see next section for a description of the explanatory variables) and unobserved heterogeneity, ε_i.[10] Various telecommunications operators of our database have not, however, reported their annual R&D expenditures. We believe that their decision whether or not to report the R&D expenditures relates to both firm- and country-specific factors (see discussion in the next section). Therefore, to obtain consistent parameter estimates, we first estimate the probability that a firm reports its R&D expenditure by the probit

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9 We may note here that the equilibrium condition of prices ($P_D = P_S$) for produced innovations in the presence of network externalities can be derived from the following (simplified) supply and demand model:

$$p_d = a_0 + a_1 RD + a_2 SALES + a_3 N(FIXED) + \alpha_4 N(CELLU) + u_1$$
$$p_s = b_0 + b_1 RD + b_2 N(FIXED) + b_3 N(CELLU) + u_2 \quad ,$$

where P_D = demand price (vector) of produced innovations and P_S = supply price (vector) of produced innovations, RD = research and development expenditures, SALES = sales revenues or demand, and N(FIXED) and N(CELLU) denote the expected network sizes of the fixed and cellular telecommunications technologies, and u_1 and u_2 denote the disturbance terms. We exclude from this simplified model various other factors - that will be discussed below - that may generally affect market supply and demand. Then, R&D expenditures can be written (in a reduced form) as follows:

$$RD = \alpha_1 SALES + a_3 N(FIXED) + \alpha_4 N(CELLU) + \varepsilon_1 \ ,$$

where ε_1 is the disturbance term.

10 We assume here that the evolution of fixed and mobile telecommunications networks is an exogenous factor. This assumption will be relaxed later on in this paper since it seems plausible that the investments of the world's prominent telecommunications operators influences the evolution of telecommunications networks (i.e. the diffusion of fixed and mobile telecommunications technologies are endogenous).

model as follows: Pr(rddmy$_{it}$)=Φ(γ'w$_{it}$), where rddmy$_{it}$ = 1 when a firm's R&D expenditures are observed and 0 otherwise, and the w$_{it}$ is the vector of variables that are assumed to explain variation in this dummy variable**.** Then, the inverse Mills ratio function of the probit residuals is used as an additional variable to explain variation in the sampled firms' R&D expenditures[11]. The R&D expenditures, RD_{it}, is a latent variable that is observed only when it is positive (and coded zero otherwise). Therefore, the density function of the R&D expenditures conditioned on ε_i can be written in two parts as follows[12]:

$$f(RD_{it}=0|x3_{it},\varepsilon_i)=\Phi(\frac{1}{\sigma_2\sqrt{1-\rho_2^2}}(\beta_3'x3_{it}-\rho_2(\sigma_2/\sigma_1)\varepsilon_i)) \quad (4a)$$

$$f(RD_{it}>0|x3_{it},\varepsilon_i)=\frac{1}{\sigma_2\sqrt{1-\rho_2^2}}\phi(\frac{1}{\sigma_2\sqrt{1-\rho_2^2}}(RD_{it}-\beta_3X3_{it}-\rho_2(\sigma_2/\sigma_1)\varepsilon_i)), \quad (4b)$$

where equations (4a) and (4b) represent the contribution to the likelihood function when $RD_{it}>0$ and $RD_{it}=1$, respectively. The vector of explanatory variables, $x3_{it}$, includes not only a firm's R&D expenditures at time t-1 (and other observable characteristics) but also the expected network sizes of fixed and cellular telecommunications technologies, $E(N(fixed))_{it}=N(fixed)_{it-1}$ and $E(N(cellu))_{it}=N_i(cellu)_{it-1}$, respectively.[13] The estimated coefficients of the installed base variables capture (potential) causality from the diffusion of fixed and cellular telecommunications technologies to the R&D expenditures.

Since the dependent variables of our system of equations are independent conditional on ε_i, the conditional joint density function of y_{it}, z_{it} and RD_{it}, $P(y_{it},z_{it},RD_{it}|X_{1it},X_{2it},X_{3it},\varepsilon_i)$, is a product of the individual density functions of the dependent variables. The unconditional probability distribution for the observed data (i.e. when z_{it}=1 and RD_{it}>0) is derived by integrating the joint density function with respect to unobserved heterogeneity, ε_i:

$$P(y_{it},z_{it}=1,RD_{it}>0|X_{1it},X_{2it},X_{3it})=\int_{-\infty}^{\infty}\frac{\exp(\lambda_{it}(\varepsilon_i))\pi_i(\varepsilon_i)^{y_i}}{y_i!}(1-(\frac{\exp(\lambda_{it}(\varepsilon_i))\pi_i(\varepsilon_i)^{y_k}}{y_k!})^{-1})$$

$$\Phi(\frac{1}{\sqrt{1-\rho_1^2}}(\beta_2'X_{2it}+(\rho_1/\sigma_1)\varepsilon_i))$$

$$\frac{1}{\sigma_2\sqrt{1-\rho_2^2}}\phi(\frac{1}{\sigma_2\sqrt{1-\rho_2^2}}(RD_{it}-\beta_3'x3_{it}-\rho_2(\sigma_2/\sigma_1)\varepsilon_i))\frac{1}{\sigma\sqrt{2\pi}}\exp(\frac{-\varepsilon^2}{2\sigma_1^2})d\varepsilon\,. \quad (5)$$

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[11] This is based on the commonly used Heckman's two-stage sample selection method (Heckman, 1979).

[12] We may note here that joint normality of the error term of the equation for the R&D expenditures, $u_{2it}\sim N(0,\sigma_2^2)$, and $\varepsilon_i\sim N(0,\sigma_1^2)$ implies: $f(u_{2it}|\varepsilon_i)=N\left[(\rho_2(\sigma_2/\sigma_1)\varepsilon_i,\sigma_2(1-\rho_2^2)\right]$.

We re-parameterize equation (5) such that $\beta_{2*} = \beta_2 / \sqrt{1-\rho_1^2}$, $\beta_{3*} = \beta_3 / \sqrt{1-\rho_2^2}$, $v_i = \varepsilon_i /(\sigma_i \sqrt{2})$, $\theta = \sigma_i \sqrt{2}$ and $\lambda_i(v_i) = \exp(\beta' X_{1i} + \theta v_i)$ and write it then as follows:

$$P(y_{it}, z_{it} = 1, RD_{it} > 0 | X_{1it}, X_{2it}, X_{3it}) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{\exp(\lambda_{it}(v_i))\pi_i(v_i)^{y_i}}{y_i!} (1 - (\frac{\exp(\lambda_{it}(v_i))\pi_i(v_i)^{y_k}}{y_k!})^{-1})$$

$$\Phi(\beta_{2*}^{'} X_{2it} + \gamma_2 v_i)\ \phi(RD_{it} - \beta_{3*}' x3_{it} - \gamma_3 v_i)\ e^{-v_i^2} dv . \qquad (6)$$

The integral of equation (6) has no closed form. We approximate it by using the Hermite quadrature[14] for integration as follows:

$$P(y_{it}, z_{it} = 1, RD_{it} > 0) \approx \frac{1}{\pi} \sum_{h=1}^{H} w_h (\frac{\exp(\lambda_{it}(v_h))\pi_i(v_h)^{y_i}}{y_i!} (1 - (\frac{\exp(\lambda_{it}(v_h))\pi_i(v_h)^{y_k}}{y_k!})^{-1})$$

$$\Phi(\beta_{2*}^{'} X_{2it} + \gamma_2 v_h)\ \phi(RD_{it} - \beta_{3*}' x3_{it} - \gamma_3 v_h)). \qquad (7)$$

The contributions to the likelihood function when $z_{it} = 0$ can be obtained similarly by using the Hermite quadrature approximation to evaluate the integrals of the re-parameterized formats of the unconditional joint density functions of z_{it} and RD_{it}.[15] The Hermite quadrature approximations when $RD_{it} > 0$ and $RD_{it} = 0$ can be written, respectively, as follows:

$$P(z_{it} = 0, RD_{it} > 0) \approx \frac{1}{\pi} \sum_{h=1}^{H} w_h (1 - \Phi(\beta_{2*}^{'} X_{2it} + \gamma_1 v_h)\ \phi(RD_{it} - \beta_{3*}' x3_{it} - \gamma_3 v_h) \qquad (8)$$

$$P(z_{it} = 0, RD_{it} = 0) \approx \frac{1}{\pi} \sum_{h=1}^{H} w_h \Phi(-\beta_{2*}^{'} X_{2it} - \gamma_1 v_h)\ \Phi(-\beta_{3*}^{'} X_{3it} - \gamma_3 v_h)) . \qquad (9)$$

The log-likelihood function of our system of equations is now:

$$\log - L = \sum_{z_{it}=1, RD_{it}>0} \log P(y_{it}, z_{it} = 1, RD_{it} > 0 | X_{1it}, X_{2it}, X_{3it}) + \sum_{z_{it}=1, RD_{it}=0} \log P(y_{it}, z_{it} = 1, RD_{it} = 0 | X_{1it}, X_{2it}, X_{3it})$$

$$+ \sum_{z_{it}=0, RD_{it}>0} \log P(z_{it} = 0, RD_{it} > 0 | X_{2it}, X_{3it}) + \sum_{z_{it}=0, RD_{it}=0} \log P(z_{it} = 0, RD_{it} = 0 | X_{2it}, X_{3it}) . \qquad (10)$$

Maximization of equation (10) results in the ML-estimates of parameters $(\beta_{1*}^{'}, \beta_{2*}^{'}, \beta_{3*}^{'}, \theta, \gamma_2, \gamma_3)$.

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13 In other words, the expected network sizes of technologies at time t are assumed to be a linear function of the installed user bases of technologies at time t-1.

14 The weights, w_h, and nodes, v_h, for the Hermite quadrature are provided, for instance, in Krylov (1962).

15 We may note here that only vectors of explanatory variables (X_{2it}, X_{3it}) are observed when $z_{it} = 0$.

We will next relax the assumption that the variables measuring network evolution of fixed and mobile communications technologies are exogenous and build an econometric model that allows their contemporaneous and inter-temporally correlated determination with innovation creation.

(ii) Endogenous network evolution and feedback effects

We assume that the network size of telecommunications technologies has a log-normal distribution and that the diffusion path of telecommunication technologies is sigmoid or that it follows a commonly used logistic growth curve (see, e.g., Stoneman, 1983):

$$N_{it} = \frac{N^*}{1+\exp(x_{it}^{'}\beta - u_{it})}, \tag{11}$$

where N_{it}= the network size of technology in the home country of a firm i at time t and N* equals the network size of technology when its diffusion is complete[16]. Equation (11) confines the expected network size, $E(N_{it})$, to the values between 0 and N*. The estimation problem may be simplified by writing equation (11) as follows:

$$\log(\tilde{N}_{it}) = x_{it}^{'}\beta + u_{it}, \tag{12}$$

where $\tilde{N}_{it} = \frac{N^*}{N_{it}} - 1$. Then, we can write - as $\tilde{N}_{it}$ is normally distributed - the density functions for the diffusion of the fixed and telecommunications networks, respectively, as follows:

$$f(N(fixed)_{it} \mid x3, \varepsilon_i) = \frac{1}{\sigma_3\sqrt{1-\rho_3^2}}\phi(\frac{1}{\sigma_3\sqrt{1-\rho_3^2}}(N(fixed)_{it} - \beta_4 X4_{it} - \rho_3(\sigma_3/\sigma_1)\varepsilon_i)) \tag{13}$$

$$f(N(cellu)_{it} \mid x4, \varepsilon_i) = \frac{1}{\sigma_4\sqrt{1-\rho_4^2}}\phi(\frac{1}{\sigma_4\sqrt{1-\rho_4^2}}(N(cellu)_{it} - \beta_5 X5_{it} - \rho_4(\sigma_4/\sigma_1)\varepsilon_i)). \tag{14}$$

Equations (13) and (14) are re-parameterized as above such that $\beta_{4*} = \beta_4/\sqrt{1-\rho_3^2}$, $\beta_{5*} = \beta_5/\sqrt{1-\rho_4^2}$, $\nu_i = \varepsilon_i/(\sigma_i\sqrt{2})$, and $\theta = \sigma_i\sqrt{2}$, where i = 3,4. They can then be written as follows:

$$f(N*(fixed)_{it} \mid x3_{it}, \nu_h) = \phi((N(fixed)_{it} - \beta_{4*}^{'}X4_{it} - \gamma_4\nu_h)) \tag{15}$$

$$f(N*(cellu)_{it} \mid x4_{it}, \nu_h) = \phi((N(cellu)_{it} - \beta_{5*}^{'}5_{it} - \gamma_5\nu_5)) \tag{16}$$

[16] We bound the upper limits of the diffusion of the fixed and cellular telecommunications networks to be one main line and one cellular telephone per inhabitant, respectively.

The log-likelihood function of the model that comprises the density function for truncated patent counts with selectivity, the density functions for the R&D expenditures and the diffusion of two network technologies is then:

$$\log-L = \sum_{z_{it}=1, RD_{it}>0} \log P(y_{it}, z_{it}=1, RD_{it}>0 \mid X_{1it}, X_{2it}, X_{3it}) + \sum_{z_{it}=1, RD_{it}=0} \log P(y_{it}, z_{it}=1, RD_{it}=0 \mid X_{1it}, X_{2it}, X_{3it})$$
$$+ \sum_{z_{it}=0, RD_{it}>0} \log P(z_{it}=0, RD_{it}>0 \mid X_{2it}, X_{3it})$$
$$+ \sum_{z_{it}=0, RD_{it}=0} \log P(z_{it}=0, RD_{it}=0 \mid X_{2it}, X_{3it}) \tag{17}$$

The ML-estimation of equation (17) produces estimates of parameters $(\beta_{1*}^{'}, \beta_{2*}^{'}, \beta_{3*}^{'}, \beta_{4*}^{'}, \beta_{5*}^{'}, \theta, \gamma_2, \gamma_3, \gamma_4, \gamma_5)$. Correlation between the equations can be estimated by using the estimated values of parameters $\theta, \gamma_2, \gamma_3, \gamma_4$ and γ_5. We use the delta method to estimate these correlation.

The next section will introduce variables used in our empirical estimations and briefly discuss their economic relevance or expected impacts on the dependent variables.

3. DATA

The database used in our empirical investigation comprises 61 major telecommunications operators from 38 countries (see Annex 1 for a list of the sampled countries). It is an unbalanced panel covering a time period from 1991 to 1996. Data are primarily extracted from The Espicom Telecommunications Operators Database and from the on-line database of the US Patent Office (http://www.uspto.gov/patft/)[17]. In addition, we have used the OECD Telecommunications Database 1997 and the book of Wellenius and Stern (1994) for collecting various aggregate-level variables (see the list of variables below).

We use the following endogenously determined variables for describing innovation behaviour of the sampled telecommunications operators:

- **PAT** = the number of patent applications a telecommunications company has filed at the US Patent Office at time t.
- **PATDMY** = 1 if a telecommunications company has filed patent application(s) at the US Patent Office at any point of time between 1991 and 1996, 0 otherwise.
- **RD** = (log) R&D expenditures of a telecommunication company at time t.

The other endogenous variables of our system of equations include the following installed user base variables:

17 As patent criteria and procedures are highly country-specific the national patent offices may not provide comparable data on patenting activities in individual countries (see, e.g., Patel and Pavitt, 1995). Therefore, we use patent data from the US Patent Office, which is generally regarded to be of high quality and to provide data on technological activities concerning the world's largest market area.

- **FIXED** = (log) $\frac{MLINE}{POP}$, where MLINE is the number of fixed main lines and POP is the number of inhabitants in the home country of a telecommunications company at time t.
- **CELLU** = (log) $\frac{CELLU}{POP}$, where CELLU is the number of the cellular telephones and POP is the number of inhabitants of the home country of a telecommunications company at time t.

The exogenous control variables comprise the following variables:

- **COMP** = (COMPL+COMPLD+COMPI)/3, where COMPL/COMPLD/COMPI = 1 if local/long-distance/international telecommunications services are open to competition in the home country of a telecommunications company at time t, 0 otherwise.
- **REGU** = 1 if the telecommunications market is regulated by an independent regulatory agency, 0 otherwise.
- **REVTOT =** (log) revenues of a telecommunications company at time t.
- **POP** = (log) the number of inhabitants of the home country of a telecommunications company at time t.
- **TIME** = time trend.
- **MILLS** = the inverse Mills ratio function of the probit residuals of the selection model for the R&D expenditures.

Section 2 motivates use of endogenously determined variables but it may be useful to clarify the role of our exogenous variables. The explanatory of variables of our primary interest concern economic policy: competition and the type of regulatory agency in the telecommunications sector. Economic theory suggests that, on the one hand, the returns from innovation via the royalties in competitive markets may act as an incentive for innovation (Arrow, 1962). On the other hand, competition may give disincentives for innovation as the more concentrated the market is or the more monopoly power the firm has, the higher the profit gains from R&D (Reinganum, 1981). Therefore, it seems credible that the degree of opening up the telecommunications sector in the country of origin of a firm influences both its scale of R&D and patenting activities. Economic theory also suggests that the deregulation of entry to the market generally increase the quantity of services or products sold, and therefore the diffusion of network technologies. We control the degree of opening up the market for competition by the variable COMP.

In addition to competition policy, another important topic that has been widely discussed is who regulates the national telecommunications markets.[18] A particularly timely question in various countries has been whether the regulator should be separate from the political decision making. Government regulation may be undesirable as it means that regulatory authorities are part of the political process (see, e.g. Stigler,

18 It has been widely acknowledged that regulation is necessary during the period of transition, when the markets are legally open to competition, but incumbent monopoly operators still have substantial market power.

1971; Peltzman, 1976; Laffont, 1994). Regulatory decisions may then vary according to the power relations of parties and provide less credibility to the stable regulatory principals in the future than an independent regulatory agency would (see Levy and Spiller, 1994). Consequently, we expect that the presence of an independent regulatory authority decrease uncertainty, and therefore increase innovation measure by R&D expenditures and patenting activities. It may also increase investments in new network technologies and thus enhance the diffusion of network technologies. The variable REGU controls for the presence of an independent regulator in the national telecommunications markets.

The variable REVTOT captures the size of a telecommunications company. We assume that the firm size is (positively) related to the order of magnitude of the R&D activities of telecommunications operators (and via that to their patenting). Also, large telecommunications operators may have a non-negligible impact on the diffusion of network technologies in the country of their origin. Therefore, the variable REVTOT is also used as an explanatory variable in the equations for the diffusion of mobile phones and fixed telecommunications lines.

The variable TIME captures the time trend or time-specific variation in the dependent variables. The variable MILLS, the mean probability that a firm's R&D expenditures is observed, is used as an additional explanatory variable in explaining the order of magnitude of the firm's R&D expenditures. In addition, we use the variable POP to explain telecommunications operators' propensity to patent in the US. This variable was selected as the potential market size or demand of a company in its home country for which the variable POP provides a proxy. We assume that domestic demand may influence a company's incentives to undertake international activities or seek profits from abroad.

Next section will discuss the empirical findings of the estimated econometric models.

4. EMPIRICAL RESULTS

We may first note that the variables FIXED and CELLU appeared to be highly correlated: the correlation between the variables was about 87 %. Therefore, as variation in these variables was assumed to explain variation in both the R&D and patent variables, we estimated the separate systems of equations (based on the equation (17)) for FIXED and CELLU as follows:

MODEL i:

$$PATENT = \beta_{10,} + \beta_{11} RD(t) + \beta_{12} RD(t-1) + \beta_{13} TIME + \theta v_h$$

$$PATDMY = \beta_{20} + \beta_{21} COMP(t) + \beta_{22} POP(t) + \gamma_2 v_h$$

$$RD = \beta_{30} + \beta_{31} RD(t-1) + \beta_{32} REVENUE(t) + \beta_{34} Ni(t-1) + \beta_{35} COMP(t) + \beta_{36} TIME$$
$$+ \beta_{37} MILLS + \gamma_3 v_h$$

$$FIXED = \beta_{40} + \beta_{41} RD(t-1) + \beta_{42} REVENUE(t) + \beta_{43} FIXED(t-1) + \beta_{44} COMP(t)$$
$$+ \beta_{45} TIME + \gamma_4 v_h$$

$$CELLU = \beta_{50} + \beta_{51} RD(t-1) + \beta_{52} REVENUE(t) + \beta_{53} CELLU(t-1) + \beta_{54} COMP(t)$$
$$+ \beta_{55} TIME + \gamma_5 v_h$$

, where i = 1,2 and N=FIXED/CELLU when i=1 and i=2, respectively. Table 1 and 2 present the ML estimates of model 1 and 2 that, respectively, use variables FIXED and CELLU as explanatory variables. The estimation results of these two models are very similar.

The incorporation of unobserved heterogeneity to the system of the estimated equations seems generally justified. The estimated coefficients of unobserved heterogeneity variables θ, γ_4 and γ_5 (see the bottom of the table) appear to be statistically significant.

Our data suggest that there is a positive and statistically significant relationship between a firm's contemporaneous R&D expenditures and the number of patent applications filed by it. The previous year's R&D expenditures, instead, do not significantly impact on firms' patenting activities. These findings are consistent with various previous empirical studies on the patent-R&D relationship (see, e.g., Hausman et al. 1984; Montalvo, 1997).

Our estimation results concerning the two independent policy variables, COMP and REGU, appear rather interesting. Our data indicates that there is a positive and statistically significant relationship between the variable COMP and a firm's propensity to file patent applications in the United States as well as the order of magnitude of its R&D expenditures. These findings provide clear evidence of the positive influence of competition for entrepreneurial innovation in the telecommunications sector.[19] Lieberman's (1987) empirical investigation of the firms in the chemical processing industries provides similar evidence; his study suggests that increased market concentration reduce firms' propensity to patent. Also, the empirical studies of Geroski (1990) and Blundell et al. (1995) suggest that competition tends to increase entrepreneurial innovations.

Our data thus suggest that a competitive environment facilitate firms' investments in research and development. The relationship between the variable COMP and PATENT is not, however, statistically significant. This empirical finding does not mean that competition do not influence firms' patenting of their innovations. Since the (current) R&D variable significantly explains variation in the patent count variable, this result also indicates that competition further (indirectly) induces utilisation of innovations in a society as patenting makes information on them publicly available. Moreover, our data suggest that liberal competition policy in the telecommunications sector has also facilitated the diffusion of cellular communications technologies. This result seems expected, since the deregulation of entry generally results in lower prices and higher quality of services and products. This happens as competition gives incentives for cost minimisation, forces prices closer to the marginal cost level and facilitates competition in terms of quality. Variation in the degree of opening up the telecommunications market to competition (COMP) does not significantly explain variation in the diffusion of the fixed telecommunications (FIXED). This is not surprising since the major telecommunications operators of various countries have typically been responsible for providing universal (basic) telephone service, irrespective of the status of competition, in their home country.

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[19] We may note here that the industry-level data from the communications sector of OECD countries between 1980-1995 did not support the hypothesis that the degree of competition affects the order of magnitude of R&D expenditures of the communications sector (see Koski, 1999b).

Quite unexpectedly, our data suggests that operators located in countries that have an independent regulatory authority in their telecommunications sector spend less on R&D than other telecommunications companies, on average. The relationship between the variable REGU and PATENT is also negative, though it is not statistically significant. These findings do not support the hypothesis that the presence of an independent regulatory authority decreases uncertainty on markets and thus increases innovation activities of telecommunications operators. On the contrary, it seems that regulatory authorities that are part of the political process provide a more favorable environment for innovation activities to large telecommunications companies. This finding might mean that the large national operators – that in various countries used to be, and are still in some countries, state-owned – are able to affect governmental regulatory decision-making in their home country. Therefore, they face more uncertainty and undertake less R&D when an independent party regulates the market.

The propensity of operators to file patent applications in the United States seems to be, instead, higher in the presence of an independent market regulator. Moreover, the penetration rates of fixed and mobile telecommunications networks are greater, on average, in countries where the telecommunications sector is regulated by an independent party. It is not clear whether governmental regulation actually hinders the diffusion of network technologies. It is also possible that countries which are diffusion-wise more advanced in their telecommunications sector development have earlier adopted politically independent regulation.

The ad-hoc chosen explanatory variables of the sample selection equation for a firm's propensity to file patent applications in the US statistically significantly explain variation in the discrete dependent variable, PATDMY. The variable POP positively relates to the variable PATDMY. It thus seems that a greater potential market size (or demand) in the country of origin of a company enhances entrepreneurial innovation in the telecommunications sector and therefore increases a firm's propensity to file patent applications. This empirical result seems reasonable as the domestic demand for telecommunications services has traditionally provided a major income source for the telecommunications operators and, in various countries, still did during the sampled time period from 1991 to 1996.

The revenues of the sampled companies clearly positively relate to their order of magnitude of R&D expenditures as the economic theory suggests. Both the expected network sizes of cellular telephones and fixed telephone lines are also positively and statistically significantly related to the R&D expenditures. This empirical finding suggests that the diffusion of mobile telephones and fixed telecommunications networks involve network externalities that enhance the R&D investments of the sampled companies. In other words, the expected returns from innovation increase with the expected installed user base of network technologies. Our data thus provides empirical evidence on the critical positive influence of the diffusion of network technologies for entrepreneurial innovation in the communications sector.

The empirical finding on the impacts of the installed user base of cellular telephones is consistent with the one of our industry-level study among OECD countries (see, Koski 1999b). Instead, our aggregate data suggested - unlike the firm-level database of this study - that variation in the installed user base of fixed telecommunications network does not statistically significantly explain variation in the R&D variable. This result may relate to the fact that the R&D expenditures of the communications sector as a whole comprise R&D investments of all communications service providers, including mobile telecommunications operators. It seems that when innovation activities of all communications service providers are included, the impact of the installed user base of fixed telecommunications networks on innovation is negligible at the aggregate level. Instead, it seems reasonable that the expected fixed network size facilitates innovation of the sampled world's major telecommunications operators since they have typically focused on providing fixed telecommunications services.

The estimated coefficient of the variable MILLS, the inverse Mills ratio function of the probit residuals from the equation explaining the probability that a firm's R&D expenditures are observed, is statistically significant. This empirical result indicates that it is important to incorporate such a mechanism to our system of equations that captures the difference between the telecommunications operators whose R&D expenditures are not observed and those that have reported their R&D expenditures. In other words, it was necessary to correct the sample selection bias related to the firms' propensity to report their R&D expenditures.

Our estimation results indicate that the revenues of the telecommunications operators are positively and statistically significantly related to the diffusion of fixed and cellular telecommunications networks in their country of origin. This finding suggests that the sampled telecommunications operators were prominent players in their national telecommunications markets during the sampled period from 1991 to 1996. It reflects their relative size or power in their country of origin: the sampled telecommunications companies are large enough to foster appreciably the evolution of fixed and mobile telecommunications infrastructure at the country level.

The variable RD(t-1), the lagged R&D expenditures, is not – unlike we expected – a statistically significant explanatory variable in the equation for the diffusion of fixed and mobile communications technologies. Since the R&D variable is firm-specific, whereas the dependent variables describe the country-level evolution of communications networks, it would seem possible that the order of magnitude of innovative activities of individual telecommunications companies is not sufficient to have an impact on the network evolution at the aggregate (country) level. This is not, however, supported by our empirical finding of the positive and statistically significant relationships between the revenue variable and the network evolution variables. Moreover, our previous study using aggregate-level data from the R&D of the communications sector and the diffusion of network technologies (Koski, 1999b) did not find a statistically significant causal effect for industrial R&D on the diffusion of fixed and mobile communications technologies. Therefore, it seems that causality is unidirectional from innovation diffusion to its creation and that network externalities play here a remarkable role.

This section has discussed the results of our empirical estimations. The next section will summarise the main empirical findings and concisely discuss their policy implications.

5. DISCUSSION AND POLICY IMPLICATIONS

This paper has empirically analysed firm-level data from 61 of the world's major telecommunications operators between the years 1991 and 1996 to investigate the direction of causality and the presence of feedback mechanisms between network evolution and entrepreneurial innovation. Altogether, our empirical findings highlight the complexity and interdependency of the system of innovation creation and diffusion in network markets.

Our data suggest that increased competitive pressures in the telecommunications sector during the 1990s has facilitated large telecommunications operators' investments in R&D and further increased their propensity to file patent applications. It indeed seems that opening telecommunications markets for competition promotes entrepreneurial innovation. Increased intensity of innovation activities of telecommunications operators may not, however, have been caused by only an intensified *actual* competition. It may also be a strategic response of the large incumbent telecommunications operators to the threat of potential new entrants. In other words, investments in R&D and patenting of new innovations may have been used as a strategic means to prevent entry of new companies to the markets. Our database does not, however, allow us to conclude whether the returns from innovation in competitive markets or the strategic prevention of entry of new competitors (or both of them) has provided a major incentive for innovation among the sampled telecommunications operators. This question would require further attention and a more extensive empirical study. It would also be interesting to explore how the innovation behaviour or strategies of the incumbent telecommunications operators and the new entrants differ from one another, and what their economic and welfare consequences to a society are.

Another interesting empirical finding concerns the role of the national regulatory agency in the creation and diffusion of communications technologies or innovations. It seems that the presence of an independent regulatory agency facilitates the diffusion of communications technologies. The relationship between innovation creation in the sampled telecommunications companies and the type of national regulatory, instead, seems less clear and requires further empirical investigations.

Our empirical exploration further indicates that the diffusion of new technologies may have substantial implications for innovation creation on network markets. Our data suggest that the diffusion of mobile telephones and fixed telecommunications networks have clearly increased the R&D expenditures of the sampled telecommunications operators. This effect is apparent even when the sales revenues or the demand of telecommunications operators is controlled for and therefore, it reflects the impact of the installed user bases of technologies on innovation creation in the communications sector. This means that the expected network size of technology, or network externalities, may matter not only in the demand and supply of network technologies but also in related innovation. Instead, we do not find any feedback effect from R&D to the diffusion of network technologies. In other words, the link between innovation creation and diffusion seems unidirectional: network externalities related to the demand for network technologies induce innovation on the supply side of network markets.

Furthermore, the results of our empirical study indicate that technology policy means facilitating the diffusion of new network technologies may also (indirectly) promote industrial R&D[20]. This suggests that supporting the diffusion of new network technologies is not necessarily an alternative policy means that shifts public resources allocated to innovation or technology policy from the promotion of innovation creation to their diffusion. Instead - since we do not find any significant causality from the determination of R&D expenditures to the diffusion of technologies – direct subsidisation of entrepreneurial R&D may not have similar indirect, positive impacts on innovation diffusion. This empirical evidence favours a current technology policy trend among OECD countries shifting emphasis from direct support of R&D towards diffusion of technologies (see, e.g., OECD, 1998).

[20] This indirect way to facilitate R&D avoids various problems related to directly subsidizing the firms' R&D investments (see Geroski, 1995 for a discussion of the problems related to subsidizing entrepreneurial R&D).

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(e.g. Stigler, 1971; Peltzman, 1976; Laffont and Tirole, 1991; Levy and Spiller, 1994).

Annex 1. List of home countries of the sampled telecommunications operators

Argentina	Japan
Australia	Korea (Rep. of)
Austria	Malaysia
Belgium	Mexico
Brazil	Netherlands
Canada	New Zealand
Canada	Norway
Chile	Peru
China	Philippines
Denmark	Poland
Finland	Portugal
France	Romania
Germany	Singapore
Greece	Spain
Hong Kong	Sweden
Hungary	Taiwan
Indonesia	Turkey
Ireland	UK
Italy	USA

Table 1. Model 1: The ML-estimates of the equations for patent count variable, sample selection mechanism, R&D and diffusion of fixed and cellular communications technologies

Variable	**LHS= PATENT**	**LHS= PATDMY**	**LHS=RD**	**LHS=FIXED**	**LHS=CELLU**
CONSTANT	-318.625 (154.861)	-6.43694 (1.54337)	397.899 (346.001)	-249.135 (155.667)	-1137.15 (162.597)
RD(t)	0.049178 (0.014579)				
RD(t-1)	-0.020125 (0.014984)		0.0054159 (0.027422)	-0.0016743 (0.014056)	-0.031662 (0.014345)
COMP	-0.144554 (0.234452)	1.01369 (0.363776)	3.27055 (0.965611)	0.134341 (0.272678)	0.705090 (0.282913)
REGU	-0.351155 (0.199216)	0.966034 (0.287860)	-2.00901 0.716629	0.556327 (0.223042)	1.18289 (0.231853)
REVENUE(t)			5.74906 (0.969670)	0.397224 (0.179428)	0.717450 (0.183133)
FIXED(t-1)			0.385890 (0.158069)	0.588210 (0.074860)	
CELLU(t-1)					0.409883 (0.053824)
POP		0.300925 (0.086662)			
TIME	0.160494 (0.077653)		-0.211354 (0.173997)	0.123805 (0.078132)	0.567369 (0.081629)
@MILLS			5.74548 (1.59903)		
Log-L	-827.36				
Number of Observations	135				
	θ=1.72666 (0.150812) γ_2=-0.187939 (0.230326) γ_3=-0.333596 (0.307622) γ_4=0.334328 (0.140653) γ_5=0.578974 (0.166080)				

Table 2. Model 2: The ML-estimates of the equations for patent count variable, sample selection mechanism, R&D and diffusion of fixed and cellular communications technologies

Variable	**LHS= PATENT**	**LHS= PATDMY**	**LHS=RD**	**LHS=FIXED**	**LHS=CELLU**
CONSTANT	-317.509 (155.325)	-6.43629 (1.54408)	328.797 (349.432)	-248.502 (155.618)	-1136.12 (162.447)
RD(t)	0.049118 (0.014573)				
RD(t-1)	-0.020167 (0.014992)		0.0058119 (0.026936)	-0.0016829 (0.014056)	-0.031632 (0.014344)
COMP	-0.143894 (0.234594)	1.01473 (0.363997)	3.20853 (0.977649)	0.134910 (0.272628)	0.706519 (0.282715)
REGU	-0.351565 (0.199465)	0.967197 (0.288112)	-2.061808 0.725783	0.555240 (0.223002)	1.18118 (0.231735)
REVENUE(t)			5.91003 (0.969500)	0.395676 (0.179368)	0.715440 (0.182976)
FIXED(t-1)				0.589212 (0.074795)	
CELLU(t-1)			0.268913 (0.112410)		0.410402 (0.053738)
POP		0.300809 (0.086692)			
TIME	0.159935 (0.077886)		-0.176755 (0.175761)	0.123490 (0.078107)	0.566856 (0.081554)
@MILLS			5.82023 (1.61481)		
Log-L	-609.03				
Number of Observations	135				
	θ=1.72628 (0.150808) γ_2=-0.195626 (0.232214) γ_3=-0.254930 (0.315249) γ_4=0.330387 (0.141237) γ_5=0.571063 (0.167915)				

SUMMARY

This paper empirically explores how technology policy affects innovation behaviour in the telecommunications sector. Our empirical analysis aims at shedding light on the following highly topical issues: (I) Whether opening up the domestic market to competition spurs innovative activity?, (ii) Whether the presence of independent regulatory agency influence innovation behaviour of telecommunications operators?, and (iii) What is the direction of Granger-causality between innovation creation and technology diffusion in the communications sector? We develop an econometric model that takes into account the dynamic, non-linear nature of the innovation process and interdependency between equations for a patent count variable, R&D and technology diffusion. We use data from 61 major telecommunications operators between the years 1991 and 1996 to investigate how technology policy has influenced their innovative activities, i.e. their R&D expenditures and the number of patent applications, and the diffusion of communications technologies in their domestic markets.

Our data suggest that opening up telecommunications markets for competition has had a clear positive impact both on innovation creation and diffusion in the telecommunications sector. Moreover, the type of regulatory agency seems to influence both innovation creation and diffusion in national communications markets. Furthermore, the results of our empirical exploration suggest that the diffusion of new technologies may have substantial implications for innovation creation on network markets. Our firm-level data do not, however, indicate any feedback effect from R&D to the diffusion of network technologies. In other words, the link between innovation creation and diffusion seems unidirectional: network externalities related to the demand for network technologies induce innovation on the supply side of network markets.