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FEEDBACK MECHANISMS IN

THE EVOLUTION OF NETWORKS:

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IN THE COMMUNICATIONS SECTOR

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Esa Viitamo

METSÄKLUSTERIN PALVELUT
- KILPAILUKYKYANALYYSI

Tutkimus on toinen väliraportti ja samalla loppuraportti Wood Wisdom –tutkimusohjelmaan kuuluvassa Metsäklusterin palvelut –hankkeessa.

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Erkki Koskela* - Markku Ollikainen**

OPTIMAL FOREST CONSERVATION:
COMPETITIVENESS VERSUS
GREEN IMAGE EFFECTS***

Forthcoming in: *Forest Science.*

* Department of Economics, P.O. Box 54 (Unioninkatu 37), FIN-00014 University of Helsinki, Finland. E-mail: Erkki.Koskela@Helsinki.fi

** Department of Economics and Management, P.O.Box 27, FIN-00014 University of Helsinki, Finland. E-mail:Markku.Ollikainen@Helsinki.fi

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Sinimaaria Ranki

DOES THE EURO EXCHANGE RATE MATTER?

I wish to extend my warmest thanks to the Research Institute of the Finnish Economy, ETLA, for providing me with an encouraging environment at their offices. I started my research while working as the Acting Professor of Economics at the University of Lapland, and was able to finish it after I had started working as the Senior Assistant at the Åbo Akademi University in Turku.

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* Department of Economics
University of Helsinki
P.O. Box 54 (Unioninkatu 37)
FIN- 00014 University of Helsinki
Finland
tel. ++358/9/1918894
fax ++358/9/1918877
erkki.koskela@helsinki.fi

** Center for Economic Studies
University of Munich
Schackstrasse 4
D-80539 Munich
Germany
tel. ++49/89/2180-2748
fax ++49/89/397303
ronnie.schoeb@ces.vwl.uni-muenchen.de
hans-werner.sinn@ces.vwl.uni-muenchen.de

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Matti Virén*

FINANCING THE WELFARE STATE IN THE GLOBAL ECONOMY

* Professor, University of Turku

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Laura Paija

ICT CLUSTER – THE ENGINE OF KNOWLEDGE-DRIVEN GROWTH IN FINLAND

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Stefan Napel* and Mika Widgrén**

INFERIOR PLAYERS IN SIMPLE GAMES†

* Institut für Wirtschaftstheorie und Operations Research (WIOR), Universität Karlsruhe (TH), 76128 Karlsruhe, Germany. Tel. +49-721-608-2697 and –3082 (fax); e-mail: napel@wior.uni-karlsruhe.de

** Turku School of Economics, Centre for Economic Policy Research (CEPR), and Yrjö Jahnsson Foundation, 00130 Helsinki, Finland. Tel. +358-9-6869 1030 and 605 002 (fax); e-mail: mika.widgren@yjs.fi, mika.widgren@tukkk.fi

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No. 735

Kari E.O. Alho

OPTIMAL FISCAL AND MONETARY POLICIES IN A RECESSION: IS THERE A WAY OUT OF THE TRAP IN AN OPEN ECONOMY?*

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No. 736

Erik Plug* - Wim Vijverberg**

SCHOOLING, FAMILY BACKGROUND, AND ADOPTION: IS IT NATURE OR IS IT NURTURE?***

* Department of Economics and Econometrics, University of Amsterdam & Department of Household and Consumer Studies, Wageningen University

** School of Social Sciences, University of Texas at Dallas

*** Correspondence to: Erik Plug, NWO program “Scholar”, Department of Economics and Econometrics, University of Amsterdam, Roetersstraat 11, 1018 WB Amsterdam, The Netherlands, e: plug@fee.uva.nl, t: +31.(0)20.5254311, f: +31.(0)20.5254310.

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No. 737

Erkki Koskela* - Matti Virén**

IS THERE A LAFFER CURVE BETWEEN AGGREGATE OUTPUT AND PUBLIC SECTOR EMPLOYMENT?***

* Department of Economics, P.O. Box 54, 00014 University of Helsinki, Finland.

** Department of Economics, 20014 University of Turku, Finland and Bank of Finland, P.O. Box 160, 00101 Helsinki, Finland.

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ABSTRACT: In the presence of network externalities, demand is strongly affected by major technology diffusion processes. Therefore, not only sales levels, but also the installed user base of network technologies may influence R&D intensity via the price mechanism. This causality may, however, not be unidirectional. This paper develops and tests an econometric model that allows both contemporaneous correlation and inter-temporal feedback between the processes of technology creation and diffusion. We use industry-level data from 1980 to 1995 to empirically explore the patterns of causality between the evolution of communications networks and the determination of the R&D intensity of the communications sectors among OECD countries.

KEY WORDS: Network effects, feedback mechanism, R&D intensity, technology diffusion

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TIIVISTELMÄ: Verkostovaikutusten luonnehtiessa markkinoita teknologioiden leviämisellä on merkittävä vaikutus markkinakysyntään. Tämän takia teknologioiden menekin lisäksi myös verkostoteknologioiden käyttäjämäärä saattaa vaikuttaa T&K -intensiteettiin markkinoiden hintamekanismin kautta. Tämä kausaalisuussuhde ei kuitenkaan ole välttämättä yksisuuntainen. Raportoitu tutkimus esittää ja testaa ekonometrista mallia, joka sallii sekä samanaikaisen korrelaation että yli ajan ulottuvan takaisinkytkennän teknologioiden kehittämis- ja leviämisprosessien välillä. Kausaalisuussuhteita viestintäverkostojen leviämisen ja viestintäsektorin T&K -intensiteetin välillä tutkitaan empiirisesti käyttäen OECD-maita koskevaa toimialatason aineistoa aikaväliltä 1980-1995.

AVAINSANAT: Verkostovaikutukset, takaisinkytkentä –mekanismi, T&K -intensiteetti, teknologioiden leviäminen

1. INTRODUCTION

The previous applied investigations of R&D intensity[1] have neglected a factor that may substantially impact on the R&D intensity in various markets: network externalities. 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).[2] The adopters value compatibility with the other users; the greater the number of users, the higher the benefits to users from the network. Since the equilibrium R&D level is determined via the price mechanism (see, e.g., Jaffe, 1986), the installed user base of network technologies may influence R&D intensity. In addition, the willingness of the individuals to pay for network technologies is affected by both the adoption behaviour of earlier user generations and the *expected* increases in the size of the installed base of users. Moreover, greater expected network size attracts a greater variety of complementary technologies supplied and thus it may further increase the user value or price of technology. The average costs may also be decreasing with the network size as the production of network technologies and services is characterised by scale economies.

Another important consideration in investigating the determination of the R&D intensity is that the processes of technology creation and diffusion are likely to be interdependent. A higher R&D intensity may lead to process and product innovations that further increase network use or the demand for communications services. In other words, it seems possible that the relationship between innovation and the network evolution are characterised by feedback. This issue, which the previous empirical studies of the diffusion and creation of innovations do not address, is of fundamental importance in understanding the inter-temporal consequences of network externalities and the innovation dynamics of network markets. This paper develops and tests an econometric model that allows both contemporaneous correlation and inter-temporal feedback between the R&D intensity and the diffusion of communications networks. We allow the dependent variables of estimated equations to be correlated via the unobservable country-specific heterogeneity terms, θ_i.

We use industry-level data from 1980 to 1995 to explore empirically the patterns of causality between the evolution of the communications networks and the determination of R&D intensity in the communications sectors among OECD countries. Our empirical estimations indicate notable contemporaneous correlation between the R&D intensity and the diffusion of fixed and cellular telecommunications technologies. Moreover, the estimated system of equations provides interesting evidence of the causality patterns between the installed user base of communications technologies and the R&D intensity. Our data do not support the presence of feedback effects between technology creation and diffu-

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1 The previous empirical studies have explored issues such as: the role of unions in the determination of R&D (see, e.g., Menezes-Filho et al., 1998); the effects of federally funded industrial R&D expenditures on privately funded R&D expenditures (see, e.g., Lichtenberg, 1987); R&D spill-overs and innovation (see, e.g., Jaffe, 1986; Griliches, 1992).

2 See, for instance, Saloner and Shepard (1995), Economides and White (1996), Majumdar and Venkatamaran (1997), Koski (1999) for empirical evidence of the impacts of network externalities on the diffusion of technologies.

sion when the R&D intensity of communications sector is measured at country level. However, when the total R&D intensity of the communications sectors of OECD countries is used as an explanatory variable, we find feedback between the installed user base of cellular telephones and the R&D intensity of the communications sector. In other words, the joint R&D efforts of OECD countries have prominently facilitated the diffusion of mobile telephones and the fast diffusion of mobile phones has further induced R&D activities in the communications sectors of OECD countries. This feedback effect may, to a large extent, explain why the global communications sector has witnessed a considerably greater increase in its R&D intensity than any other industrial sector during the 1990s.

The paper is organized as follows. Section 2 develops an econometric model for the interdependent determination of innovation and network evolution in the communications sector. Section 3 introduces the database used in our empirical investigation. Section 4 discusses the estimation results. Section 5 concludes the paper.

2. ECONOMETRIC MODEL OF THE FEEDBACK MECHANISMS IN THE COMMUNICATIONS SECTOR

The impact of demand on R&D expenditures is typically estimated by using a variable that controls for total sales (see, e.g., Jaffe, 1986). In the presence of network externalities, not only the sales level but also the expected network size may influence R&D expenditures. We consider two communications technologies to be particularly prominent in the communications sector: the fixed and cellular telecommunications technologies. A simplified model for R&D expenditures of the communications sector can then be written as follows:[3]

$$RD = \alpha_1 SALES + a_3 N(FIXED) + \alpha_4 N(CELLU) + \varepsilon_1 \ , \tag{1}$$

where 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 ε_1 is the disturbance term.

A higher R&D intensity may lead to the process and product innovations that further increase network use or the demand for communications services. In other words, it seems possible that the relationship between the processes of technology creation and dif-

[3] We may note here that equation (1) is the reduced form that is derived by solving the equilibrium condition of prices ($P_d = P_s$) from the following (simplified) supply and demand model for produced innovations in the presence of network externalities:

$$p_d = a_0 + a_1 RD + a_2 N(SALES) + a_3 N(FIXED) + \alpha_4 CELLU + u_1$$

$$p_s = b_0 + b_1 RD + b_2 N(FIXED) + b_3 N(CELLU) + u_2 \ ,$$

where P_d = demand price (vector) of produced innovations and P_S = supply price (vector) of produced innovations, and u_1 and u_2 denote the disturbance terms. We exclude from this simplified model various other factors - discussed below - that may affect supply and demand in the (network) markets.

fusion is not unidirectional.[4] We employ Granger's (1969) definition of causality in exploring the causal patterns between the R&D intensity and network evolution: 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.

We will next develop an econometric model that is used for investigating the patterns of causality between the R&D intensity of the communications sector and the network size of the fixed and cellular telecommunications networks. Our econometric model will allow both contemporaneous correlation and inter-temporal feedback between the processes of technology creation and diffusion. We allow the dependent variables of the three equations - the R&D intensity, and the diffusion of fixed and mobile telecommunications technologies - to be correlated via unobservable country-specific heterogeneity terms, θ_i. The dependent variables are determined independently from one another conditional on unobservable heterogeneity term that impacts their mean values. We assume that θ_i remain constant over time. We will first describe each component of the system of the three interdependent equations and then present the joint density function of the equations.

The R&D intensity of a communications sector of country i at time t depends on the expected network size of fixed and cellular telecommunications networks, other observable characteristics of the industry (described in the next section), and on the unobservable country-specific characteristics of the communications industry, θ_i.[5]

The R&D expenditures are not observable in a number of cases due to the cross-country differences in reporting and collecting the aggregate industrial R&D statistics. We truncate unobserved R&D values to zero and use Heckman's two-stage sample selection method as follows. We first estimate the probability that the communications industry's R&D statistics are reported using the following probit model:

$$\Pr(z_{it})=\Phi(\gamma' w_{it}), \tag{2}$$

where $z_{it} = 1$, when R&D expenditures are observed and 0 otherwise, and the w_{it} is the vector of variables (see Section 3) that are assumed to potentially affect the propensity to systematically collect the R&D statistics from the communications sector of country i. Then, we use the inverse Mills ratio function of the probit residuals - which captures the mean probability that R&D is observed - as an additional explanatory variable in explaining the R&D intensity. The density function of R&D intensity is determined as follows:

$$f(RD)_{it} \left| x1_{it}, \theta_i \right) = \prod_{i=1}^{n} \frac{1}{\sigma_1} \exp\left(\frac{\chi_{f1} N(fixed)_{it-1} - \chi_{c1} N(cellu)_{it-1} - \beta' x1_{it} - \theta_i}{\sigma_1}\right), \tag{3}$$

[4] This means that the network size is an endogenous determinant of the R&D intensity. Consequently, the OLS estimation of equation (1) would involve a problem of endogeneity bias.

[5] Unobservable differences in the R&D intensity of the communications sectors may arise, for instance, from the country-specific tax treatment of industrial R&D.

where $N_i(cellu)_{t-1}=E(N_i(cellu)_t)$ and $N_i(fixed)_{t-1}=E(N_i(fixed)_t)$ denote the expected network sizes of cellular and fixed communications technologies, respectively, in country i. We assume that the expected network sizes of technologies at time t are a linear function of their installed user bases at time t-1. The estimated coefficients γ_1 and γ_2 provide information on causality from technology diffusion to creation of new technologies and innovations.

The diffusion paths of fixed and cellular telecommunication technologies are assumed to follow the logistic growth curve (i.e. to be sigmoid):

$$N_{it} = \frac{N^*}{1+\exp(\chi_1 N_{it-1} - \chi_2 RD_{it-1} - \beta' x_{it} - \theta_i)}, \qquad (4)$$

where N_{it}= the network size of technology in a country i at time t and N* equals the network size of technology when its diffusion is complete. Equation (3) confines the expected network size, $E(N_{it})$, to the values between 0 and N*. This means that N_{it} has a log-normal distribution. The coefficient of variable RD_{it-1} gives information of causality from the R&D intensity to the diffusion of technologies. Equation (4) can be written in the form that simplifies the estimation problem as follows:

$$\log(y_{it}) = \chi_1 N_{it-1} - \chi_2 RD_{it} + \beta' x_{it} + \varepsilon_{it} - \theta_i, \qquad (5)$$

where $y_{it} = \frac{N^*}{N_{it}} - 1$. The upper bounds of the diffusion of the fixed and cellular telecommunications networks are assumed to be one main line and one cellular telephone per inhabitant, respectively. Then, we can write - as y_{it} is normally distributed - the density functions for the diffusion of the fixed and cellular telecommunications networks, respectively, as follows:

$$f(N(fixed)_{it} | x2_{it}, \theta_i) = \prod_{i=1}^{n} \frac{1}{\sigma_2} \exp\left(\frac{\chi_{f1} N(fixed)_{it-1} - \chi_{f2} RD_{it-1} - \beta' x2_{it} - \theta_i}{\sigma_2}\right), \qquad (6)$$

$$f(N(cellu)_{it} | x3_{it}, \theta_i) = \prod_{i=1}^{n} \frac{1}{\sigma_3} \exp\left(\frac{\chi_{c1} N(cellu)_{it-1} - \chi_{c2} RD_{it-1} - \beta' x3_{it} - \theta_i}{\sigma_3}\right), \qquad (7)$$

where $N(fixed)_{it}$ and $N(cellu)_{it}$ are the number of fixed telecommunications main lines and the number of cellular telephones per inhabitants, respectively, in country i at time t, and $x2_{it}$ and $x3_{it}$ denote the sets of observable dependent variables.

The joint density function of the determination of the R&D intensity, the diffusion of the fixed and cellular telecommunications network can then be written as a product of equations (3), (6) and (7) as follows:

$$f(N(fixed)_{it}\, N(cellu)_{it}, RD_{it} \big| x1_{it}, x2_{it}, x3_{it}, \theta_i) =$$

$$\prod_{i=1}^{n} \frac{1}{\sigma_2} \exp\left(\frac{\chi_{f1} N(fixed)_{it-1} - \chi_{f2} RD_{it-1} - \beta' x2_{it} - \theta_i}{\sigma_2}\right) \prod_{i=1}^{n} \frac{1}{\sigma_3} \exp\left(\frac{\chi_{c1} N(cellu)_{it-1} - \chi_{c2} RD_{it-1} - \beta' x3_{it} - \theta_i}{\sigma_3}\right)$$

$$\prod_{i=1}^{n} \frac{1}{\sigma_1} \exp\left(\frac{\chi_{f1} N(fixed)_{it-1} - \chi_{c1} N(cellu)_{it-1} - \beta' x1_{it} - \theta_i}{\sigma_1}\right). \tag{8}$$

The unconditional joint density of RD_{it}, $N(fixed)_{it}$ and $N(cellu)_{it}$ is derived by integrating the conditional joint density of equation (8) with respect to the vector of unknown densities of unobservable heterogeneity terms, $\theta = (\theta_1, \theta_2, \theta_3)$. We assume that θ_i has a discrete density, (π_k, θ_k), where k=1,...,K denotes the number of points of support of the density of θ, π_k describes the corresponding probabilities of the points of support and $\theta_k = (\theta_{1k}, \theta_{2k}, \theta_{3k})$. A multitude of heterogeneity distributions can be captured by the discrete factor approximation. We assume k=1,2 in our model, since the previous empirical studies suggest that satisfactory parameter estimates can be obtained by assuming a small number of points of support for the density of θ (see, e.g., Steiger and Wolak, 1994). We may present the unconditional joint density or likelihood function of the dependent variables as follows:

$$L(RD_{it}, N(fixed)_{it}, N(cellu)_{it}) = \sum_{k=1}^{2} \pi_k\, pr(RD_{it}, N(fixed)_{it}, N(cellu)_{it} | \theta_k, x1_{it}\, x2_{it}, x3_{it}). \tag{9}$$

The log-likelihood function of the model we have estimated is obtained by taking the logarithm of equation (9).

3. DATA

Our database originates from four different sources. The financial and network variables are extracted from the OECD Telecommunications Database 1997, R&D expenditures are based on the ANBERD Database (OECD), and information for the policy variables is collected from the book of Wellenius and Stern (1994) and the Espicom Telecommunications Operators Database. The total telecommunications revenues of the operators of 15 sampled countries (see Annex 1 for the list of countries) cover about 94 % of the total revenues of the operators in OECD countries during the period of 1980-1995**.** We will next discuss the variables used in our empirical exploration.

Dependent variables:

Our empirical model comprises the following three endogenous variables:

We create a variable for the R&D intensity of the communications sector as follows:

- **DRD72** = a first difference of (log) RD/REV,

  where RD = R&D expenditures of the communication sector (ISIC 72) of a country at time t and DREV = the total revenues in the telecommunications sector (ANBERD database).

- **DFIXED** = a first difference of (log) $\frac{1}{FIXED / POP} - 1$, where FIXED is the number of fixed main lines and POP is the number of inhabitants of a country at time t (OECD Telecommunications Database 1997). [6]

- **DCELLU** = a first difference of (log) $\frac{1}{CELLU / POP} - 1$, where CELLU is the number of the cellular telephone and POP is the number of inhabitants of a country at time t (OECD Telecommunications Database 1997).

  The **exogenous control variables** of our model are the following:

- **DRD38** = difference of the log RD38, where RD38 = R&D expenditures of the office & computing equipment sector (ISIC 3825) and the radio, TV & communications equipment sector (ISIC 3832) of a country at time t (ANBERD Database).
- **COMP** = (COMPL+COMPLD+COMPI)/3,

  Where COMPL/COMPLD/COMPI = 1 if local/long-distance/international Telecommunications services are open to competition, 0 otherwise.
- **REGU2** = 1 if the telecommunications market is regulated by an independent regulatory agency, 0 otherwise.
- **TIME** = time trend.
- **MILLS** = the inverse Mills ratio function of the probit residuals of the selection model for the R&D expenditures of the communications sector.

We first note that not only the R&D intensity of the communications sector of a country but also the total R&D intensity of the OECD communications sector may influence the diffusion speed of network technologies in each country. This may happen due to notable international R&D collaboration among the communications sector of OECD countries that creates R&D spill-overs between the countries.[7] Therefore, we also estimate the system of equations where a first difference of the total R&D intensity of the communications sectors of OECD countries is an explanatory variable.

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[6] Unfortunately, we do not have data concerning the number of fixed telephone network subscribers. However, we believe that the number of main fixed telephone lines provides a good proxy for the installed user base of the fixed telecommunications network.

[7] One landmark of the development towards co-operation among OECD countries was the establishment of Information, Computer, and Communications Policy (ICCP) Committee, which aimed at strengthening co-operation among the member countries of OECD regarding communications field, in 1984.

We believe that the order of magnitude of R&D in the communications sector is related to the technical progress of its major input providers,[8] the office and computing equipment sector and the radio, TV and communications equipment sector. Technological progress in these sectors (especially in microelectronics) may provide new opportunities for innovation in the telecommunications sector (e.g. digitisation) and enhance innovative activities or the R&D intensity of the communications sector. The R&D spill-overs are captured by the variable DRD38, which is a first difference of R&D expenditures of the office and computing equipment sector and the radio, TV and communications equipment sector.

We will also control for two relevant policy factors: competition and the type of regulatory agency. On the one hand, competition may give incentives for innovation: the returns from innovation via royalties encourage innovation in the competitive markets (Arrow, 1962). On the other hand, the more concentrated the market is or the more the firm has monopoly power, the higher the profit gains from R&D (Reinganum, 1981). The empirical studies (see, e.g., Kamien and Schwartz, 1975; Colombo and Mosconi, 1995) provide conflicting evidence on the impact of the market structure on the firms' innovative behaviour.

The communications sectors of OECD countries have basically two types of regulatory authorities: the independent regulatory authorities and government departments acting as regulators. Government regulation is often regarded undesirable as it means that regulatory authorities are part of the political process (see, e.g. Stigler, 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, the presence of an independent regulatory authority may decrease uncertainty and increase innovation and R&D expenditures. The degree of opening up the market for competition and the type of regulatory agency are captured by the variables COMP and REGU, respectively. Table 1 shows the descriptive statistic measures, mean and standard deviations of the variables used in the empirical estimations.

The variable MILLS, the mean probability that the R&D expenditures is observed, is derived from the estimation of the probit model of equation (2). The propensity to systematically collect the R&D statistics from the communications sector is assumed to depend on the following (ad hoc selected) variables: the importance of the communications sector for the economy measured by the (log) communications revenues divided by the GDP of a country, and the institutional and policy factors, competition and the type of regulatory agency (REGU, COMP). The variable MILLS is used as an additional explanatory variable in explaining the R&D intensity variable.

Before discussing the estimation results of our econometric model, we will show the graphical presentation of the time series of endogenous variables.

[8] See, for instance, De Bondt (1996) for discussion on economic modelling of spill-overs and innovative activities.

- FIGURE 1-3 ABOUT HERE –

Figure 1 illustrates the average R&D expenditures of the communications sector from 1980 to 1995 among the sampled OECD countries (see Annex 1 for the list of countries). An increase in the R&D expenditures has been slow during first half of the 1980s, but since 1985 the OECD communications sector has witnessed a tremendous increase. It is also useful to demonstrate the plots of the time series of the (average) number of main telephone lines and the number of cellular subscribers in the sampled countries from 1980 to 1995. Figures 2 and 3 illustrate that the average number of main telephone lines has increased linearly from 1980 to 1995, whereas the growth in the cellular subscriptions seems exponential. The growth patterns of R&D expenditures of the communications sector and the number of cellular subscribers seem to be very similar: slow growth during the first half of the 1980s followed by vigorous expansion until mid 1990s (the end point of our data).

4. ESTIMATION RESULTS

This section will provide the estimation results of the econometric model developed in the previous section. Figures 1-3 indicate that there is an increasing trend in (average) R&D expenditures and the (average) penetration rates of fixed telephone lines and cellular telephones. This suggests that the three series are not stationary, and consequently, that asymptotic theory does apply unless the trend is eliminated. The Dickey-Fuller test was used for testing whether the time series are trend-stationary or difference-stationary (see, e.g., Harvey, 1990).[9] We tested the non-stationary hypothesis H_0: $\rho=1$ by estimating the following OLS equation for the dependent variables: $X_t = \alpha + \rho X_{t-1} + \varepsilon_t$, where X_t = (log) the value of a dependent variable at time t. Then, we calculated the following t-test value for each dependent variable: $t = (\hat{\rho} - 1)/\sigma_\rho$. The calculated t-value for the R&D intensity (-2.64) was lower than its critical value indicating that hypothesis H_0 cannot be rejected at the 0.05 level of significance. In other words, the series of the R&D expenditures was difference-stationary. This result implies that the best method for eliminating the trend is differentiation. Instead, the t-values for the series of the diffusion of mobile phones and fixed telephone lines (-5.73 and –3.54, respectively) suggest that differentiation would not be necessary if the equations for these two series were estimated independently. However, it is reasonable to differentiate all three series in order to be consistent in the estimation of our system of equations that investigates the relationships between the three dependent variables.

Table 2 presents the estimation results of the logarithm of equation (9). Our estimation results suggest that endogenous variables are clearly correlated with one another. Contemporaneous correlation between the R&D intensity variable and the installed base of users of the fixed and mobile telecommunications networks are statically significant (60 % and 28 %, respectively). The diffusion processes of cellular and fixed telecommunications technologies are also closely related to one another; the estimated correlation between the variables DCELLU and DFIXED is statically significant as well (46 %). In other words, there exist significant complementary between the diffusion of fixed and cellular communications technologies. Moreover, this finding supports the view that creation and diffusion of technologies are determined interdependently.

The estimated system of equations provides interesting evidence of the direction of causality between the installed user base of communications technologies and the R&D intensity. The estimated coefficient of the variable $DCELLU_{t-1}$ is positive and statistically significant suggesting that the expected network size of the cellular telephone users has a non-negligible, positive influence for the R&D intensity of the communications sector. The variable $DFIXED_{t-1}$ is not statistically significantly related to the R&D intensity variable. There are several potential explanations for these empirical results. First, it seems possible that the order of magnitude of network externalities related to cellular

[9] When a series is trend-stationary, it is possible to eliminate the trend by regressing the series - in addition to other explanatory variables - by time. In the case of difference-stationary series, the usual least square theory is not valid; differentiation is necessary for eliminating the trend and obtaining efficient estimates.

telephone use are greater than those related to fixed telephone network use since the cellular telephone - unlike the fixed telephone line - allows the user to be connected or reached irrespective of his physical location. Consequently, the value to the user of buying a cellular telephone may be higher than it would be if he subscribed to a fixed telecommunications line. Second, this empirical finding may relate to the different stages of the diffusion paths of mobile phones and fixed telephone lines. The market for fixed telephone connections has been much mature than that for mobile phones during the sampled years. Therefore, an expected increase in demand for mobile telephones has been much higher than the expected growth in the diffusion of fixed telephone lines. This might have induced R&D investments in mobile communications.

The variable $DRD72_{t-1}$ is statistically significantly related neither to the diffusion of fixed telecommunication technology nor to the diffusion of the cellular telephones. However, the estimation of the systems of equations where a first difference of the total R&D intensity of the communications sectors of OECD countries was an explanatory variable gave a different result.[10] Our data suggested that there is a positive and statistically significant relationship between the total R&D intensity of the communications sector of OECD countries and the diffusion of mobile telephones. Thus, it seems that there occurs feedback between the diffusion of mobile telephones and R&D undertaken within the OECD communications sector. Our empirical findings further stress the important role R&D collaboration among OECD countries has played in the development of their communications sectors.

The estimated coefficient of the variable $DRD38_{t-1}$ does not statistically significantly explain variation in the R&D intensity of the communications sector. This empirical finding suggests that the office and computing equipment sector and the radio, TV and communications equipment sector may not provide significant direct R&D spill-overs to the communications sector. However, our data suggest that R&D spending of the office and computing equipment sector and the radio, TV and communications equipment is positively related to the diffusion of the fixed telecommunications networks. This result seems reasonable since the development and provision of fixed telecommunications infrastructure and services are highly dependent on technological progress, for instance, in electronics (e.g., lasers cannot emit a pulse more rapidly than the circuits that control them). Also, progress in microelectronics is important in determining the prices and quality of fixed telecommunications network use and therefore, the variety of new services provided via the fixed telecommunications networks.

Our data suggests that the degree of competition influence neither the order of magnitude of R&D expenditures of the communications sector nor the diffusion of communications technologies. On the one hand, this means that our data provide no evidence that competition facilitates diffusion or creation of innovations. On the other hand, this result suggests that competition does not diminish innovation - as suspected and feared by some parties - in the communications sector.

We expected that regulatory decisions of an independent regulatory agency might provide more certainty on the communications market than government regulation and

[10] These empirical results are available from the author upon request. They do not otherwise notably differ from those of Table 1 expect with respect to the R&D intensity variable.

therefore facilitate industrial innovation and technology diffusion. The estimated coefficients of the variable REGU do not, however, statistically significant explain any of our dependent variables. Our data do not thus support the hypothesis that the independent regulatory authority would provide a more favourable environment for technology creation and diffusion than do the departments of governments acting as regulators.

The next section will briefly discuss the main findings of our empirical analysis.

5. CONCLUSIONS

This paper has developed an econometric model of the joint determination of the R&D intensity of the communications sector and the diffusion of communications technologies. Our econometric model allows both contemporaneous correlation and intertemporal feedback between the processes of technology creation and diffusion. We have explored the patterns of causality between the evolution of the communications networks and the determination of the R&D intensity of the communications sectors among OECD countries.

Our empirical estimation results imply clear contemporaneous correlation between the R&D intensity variable and the installed base of users of the fixed and cellular telecommunications networks. This means that there exist significant interdependency between creation and diffusion of communications technologies. Also, our data suggest complementarity between the diffusion of different communications technologies. Our data do not support the presence of feedback effects between technology creation and diffusion when the R&D intensity of communications sector is measured at country level. However, when the total R&D intensity of the communications sectors of OECD countries is used as an explanatory variable, we find feedback between the installed user base of cellular telephones and the R&D intensity in the communications sector. In other words, the joint R&D efforts of OECD countries have prominently facilitated the diffusion of mobile telephones and the fast diffusion of mobile phones has further induced R&D activities in the communications sectors of OECD countries. This feedback effect in the rapidly growing cellular markets may explain why the global communications sector has witnessed a considerably greater increase in its R&D intensity than any other industrial sector during the 1990s. More generally, this finding indicates that network externalities may have a notable accelerating impact on industrial innovation.

The empirical exercise of this paper suggests that interdependency in network markets may have substantial economic consequences. We note, however, that since our estimation results are based on aggregate-level data, the results reported in this paper should be interpreted with caution. It would be useful to test the ideas and the econometric model of this paper with a firm-level data set.

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Annex 1. List of countries

Australia
Canada
Denmark
Finland
France
Germany
Ireland
Italy
Japan
Netherlands
Norway
Spain
Sweden
United Kingdom
United States

Table 1. Descriptive statistics

Variable	Mean (Std.Dev.)
DRD72	0.034440 (0.20020)
DFIXED	0.017568 (0.10383)
DCELLU	0.15810 (0.18115)
DRD38	0.14724 (0.59807)
COMP	0.19589 (0.36918)
REGU2	0.16895 (0.37557)

Table 2. The ML estimates of the models for the R&D intensity of the communications sector and the diffusion of fixed and mobile communications technologies

Variable	MODEL 1		
	DRD72	DFIXED	DCELLU
Constant	2.43143 (4.45722)	2.79413 (0.705122)	-11.8120 (6.36571)
DFIXED(t-1)	0.00700803 (0.061440)	0.135785 (0.030890)	
DCELLU(t-1)	0.029468 (0.011481)		0.260389 (0.067137)
DRD38(t-1)	0.0372821 (0.028166)	0.0092745 (0.00360823)	-0.00711862 (0.028403)
DRD72(t-1)	0.036239 (0.059899)	0.00463889 (0.00998933)	0.00574522 (0.084721)
COMP	-0.055883 (0.030985)	-0.0050685 (0.00503080)	0.010475 (0.044586)
REGU	0.019170 (0.030419)	-0.0028419 (0.00494643)	-0.022437 (0.043743)
TIME	-0.0012157 (0.0022431)	-0.0013905 (0.00093546)	0.0060067 (0.00320365)
MILLS	0.029468 (0.011481)		
Nobs	210		
Log-L	736.37		
Correlation	ρ(drd72, N(dfixed))= 0.930131 ρ(drd72, N(dcellu)) = 0.813161 ρ(N(dfixed), N(dcellu)) = 0.870771		

SUMMARY

In the presence of network externalities, demand is strongly affected by major technology diffusion processes. Therefore, not only sales levels, but also the installed user base of network technologies may influence R&D intensity via the price mechanism. This causality may, however, not be unidirectional. This paper develops and tests an econometric model that allows both contemporaneous correlation and inter-temporal feedback between the processes of technology creation and diffusion. We use industry-level data from 1980 to 1995 to empirically explore the patterns of causality between the evolution of communications networks and the determination of the R&D intensity of the communications sectors among OECD countries.

The estimated system of equations provides interesting evidence of the causality patterns between the installed user base of communications technologies and the R&D intensity. Our data do not support the presence of feedback effects between technology creation and diffusion when the R&D intensity of communications sector is measured at country level. However, when the total R&D intensity of the communications sectors of OECD countries is used as an explanatory variable, we find feedback between the installed user base of cellular telephones and the R&D intensity of the communications sector. In other words, the joint R&D efforts of OECD countries have prominently facilitated the diffusion of mobile telephones and the fast diffusion of mobile phones has further induced R&D activities in the communications sectors of OECD countries. This aggregate-level feedback effect may, to a large extent, explain why the global communications sector has witnessed a considerably greater increase in its R&D intensity than any other industrial sector during the 1990s.