MOBILE COMMUNICATION IN FINLAND: ANALYSIS OF THE DIFFUSION PROCESS IN A FIRST-MOVER COUNTRY

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ABSTRACT

In this paper the diffusion of mobile communication in Finland is studied. The objectives are to find factors which have affected the diffusion process, and to forecast the diffusion of mobile communication in Finland. The diffusion process is based on the theory of epidemic diffusion. The data consists of annual mobile subscribers of networks based on NMT and GSM standards in 1981–1998. The data is fitted into the logistic model by means of non-linear least squares, after writing two parameters of the logistic model as functions of variables. The results show that the economic situation has affected the relative growth rate, and that the mobile network coverage has affected the number of potential adopters. Forecasts of mobile communication in Finland are made by extrapolating the logistic model, additionally, a confidence interval for the forecast is calculated. The forecast shows that the final penetration rate will be some 91.7 % in 2009. Finally, the time derivatives of the diffusion process are determined by dimensional analysis as velocity and acceleration, which are analyzed further.

Keywords: technological diffusion, mobile communication

1 INTRODUCTION

Finland's role as a first-mover in mobile communication makes its diffusion path special: knowledge of the diffusion path could possibly be used in studying followers' diffusion paths. The objectives of this paper are 1) to find factors, which have affected the diffusion of mobile communication, and 2) to forecast the diffusion of mobile communication in Finland.

The theory of innovation diffusion suggests an S-shaped curve for an innovation's diffusion path: in the beginning the diffusion is slow, in the mid-phase it is fast and in the it is end slow again. The form of an innovation's diffusion path is based, e.g., on contagious information. Thus the S-shaped diffusion is also known as epidemic diffusion.

Koski (1999) divides economic micro-approaches (models of adoption timing) to diffusion of innovations into three categories: decision-theoretic, game-theoretic and network externality models. An additional category is formed by information based models, which can be divided further by the nature of the contagion: in passive (epidemic) models the adopter does not actively seek information about the innovation, whereas active information models are based, e.g., on information demand (Tonks 1986). Based on this categorization, the upper part (micro-approach) of figure 1 can be formed.

Mahajan & Peterson (1985) base their division of macro-level models of innovation diffusion into three categories on the way information about the innovation spreads: 1) without contagion, 2) epidemic contagion and 3) mixed models. Categories 2) and 3) can be divided further into subcategories by the form of the diffusion model. This categorization forms the lower part (macro-approach) of figure 1.

Empirical research of innovation diffusion in economics is usually based on epidemic contagion, using either the logistic or Gompertz-model. The goal is to find economic variables affecting the diffusion and to determine the final diffusion level. Griliches (1957) was first to empirically study the innovation diffusion paradigm in economics. He studied the diffusion process of hybrid corn and showed that profitability as an economic variable had affected the diffusion process. Afterwards, several innovations' diffusion processes have been studied. Recent studies explore, e.g., the diffusion of industrial robots in Japan and USA (Mansfield 1989), of shutleless loom (Gruber 1998) and of mobile communication services in the EU (Gruber & Verboven 1999).

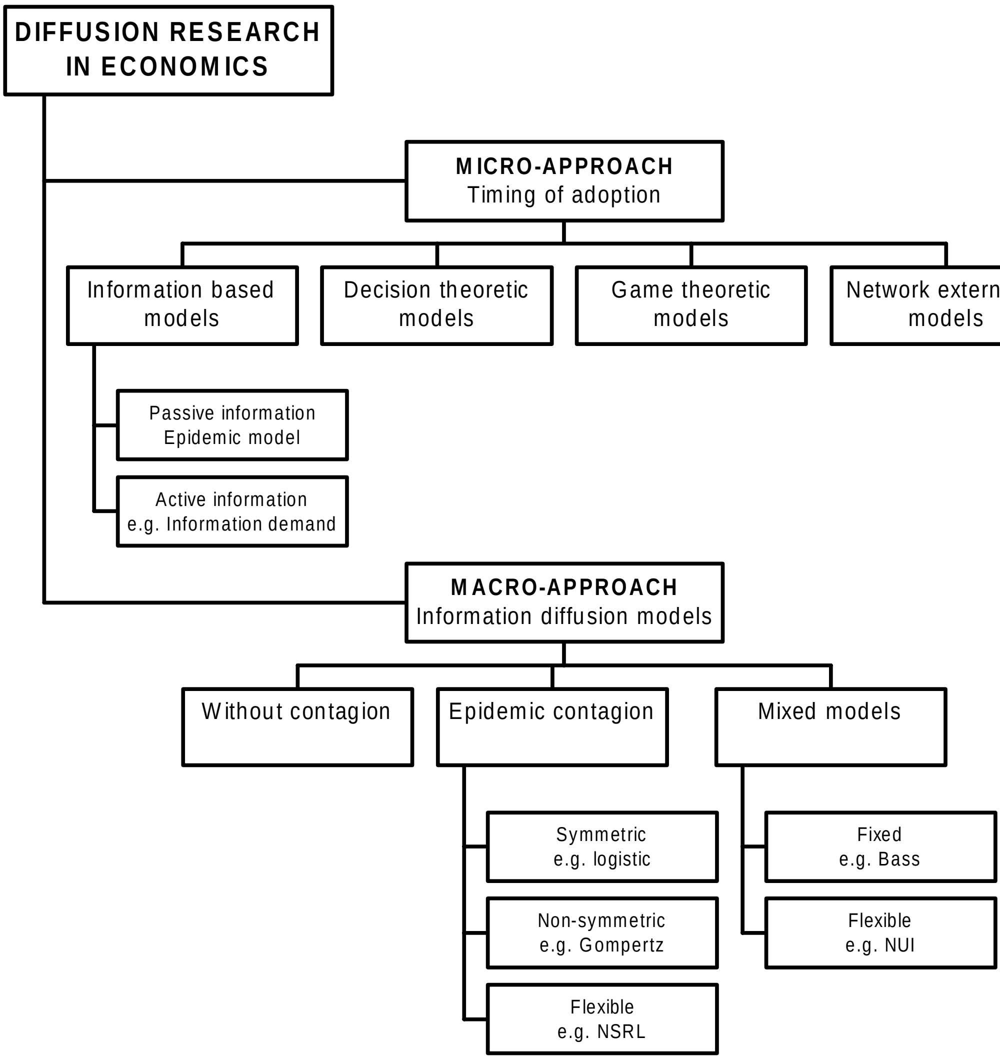

Figure 1. Classification of economic diffusion research approaches.

In Finland the era of mobile communication began with the analogous NMT-standard (Nordic Mobile Telephone) in 1982. The standard was developed by the Nordic countries, and later adopted by several other countries around the world. As analogous standards proved to be inefficient, the European Post and Telecommunication Conference came up with the digital GSM standard (Global System for Mobile Communication). Finland adopted the GSM-standard among the first countries in 1992. The digitality of the GSM-standard made data transfer possible, which in turn enabled, e.g., SMSmessages. Furthermore, simultaneously with the GSM standard, the EU instructed competition in the Finnish mobile network operator market.

2 THE ECONOMETRIC MODEL OF DIFFUSION

The data used in this study is from MINTC (1999): it consists of annual mobile subscribers, including both NMT and GSM standards. The observed time period is 1982–1998, added with an observation of zero in 1981, which resulted in 18 observations. The number of observations is small, but because the objective was to study mobile communication in Finland no other data was added. The data was fitted in the following equation by means of non-linear least squares:

$$(1)\quad y_t = \frac{y*_t}{1+e^{-(a+b_t t)}}.$$

Equation (1) is known as the logistic model, which was developed for population growth forecasting purposes by Pierre-François Verhulst in 1843. In equation (1), y_t is the number of mobile subscribers in time period t. Additionally, the logistic model of equation (1) has three parameters: $y*$, b and a. Parameter $y*$ measures the number of potential adopters, which is approached by the logistic model as time passes:

$$(2)\quad \lim_{t\to\infty} y(t) = \lim_{t\to\infty}\left(\frac{y*}{1+e^{-(a+bt)}}\right) = y*.$$

Parameter b can be determined as follows: after differentiating and rearranging equation (1) can be transformed into:

$$(3)\quad b = \frac{\frac{dy}{dt}\Big/ y(t)}{(y*-y)/y*}.$$

Now, the nominator of equation (3) is the growth rate of the diffusion process, and the denominator is the fraction of potential adopters, into which the innovation has not diffused yet. Parameter b can thus be interpreted as the relative growth rate: it is the growth rate of the diffusion relative to not-yet adopted fraction of potential adopters. Finally, parameter a determines the timing of the diffusion process by shifting the logistic model in time.

The number of potential adopters was defined as a fraction of people living in areas covered by the mobile network:

(4) $y*_t = \gamma \cdot X_t^a$.

In equation (4), γ is a coefficient and variable X_t^a is calculated by multiplying the annual percentage of people living in areas covered by the mobile network with the Finnish population. The data on the amount of population living in areas covered by the mobile network is from the Finnish network operator Sonera. Although not fully realistic, this model is more realistic than one assuming the potential adopters to remain constant over the diffusion period. The relative growth rate of the diffusion was defined as follows:

(5) $b_t = \beta_a + \beta_b \cdot X_t^b + \beta_d \cdot X_t^d + \beta_k \cdot X_t^k$.

The variables and hypotheses of equation (5) are as follows: X_t^b is GDP per capita, which measures the economic situation. It is assumed to be positively correlated with the relative growth rate: the better the economic situation, the greater the relative growth rate. Variable X_t^d measures the effect of digitalization and competition. It is a dummy variable, its value being zero before the introduction of GSM and one after it. Digitalization and competition are also assumed to be positively correlated with the relative growth rate. Finally, X_t^k measures the number of fixed lines. It is used to test the relationship between mobile and fixed communication: if the coefficient gets a positive sign, they are complements (the more fixed lines, the greater the growth rate of mobile diffusion); a negative sign would indicate that they are substitutes. The corresponding β:s are the estimated coefficients for the variables.

3 ESTIMATION RESULTS

The results of estimating equation (1) after adding an error term are listed in table 1.[1] The unrestricted model includes all the variables described above. The estimation results for the unrestricted model indicate that, additionally to the constants, only the variable measuring the economic situation was statistically significant. Consequently, a restricted model, with insignificant variables omitted, was estimated.

Table 1. Estimated coefficients and standard errors in parentheses. Statistical significance at 95 % confidence level is marked by an asterisk.

Variable	Model	
	Unrestricted	Restricted
α	-5.796* (0.346)	-5.837* (0.118)
β_a	0.007 (0.171)	0.064* (0.021)
GDP X_t^b	2.121* (0.244)	2.193* (0.145)
Digitality X_t^d	0.022 (0.054)	-
Fixed lines X_t^k	-0.001 (0.006)	-
Fraction γ	0.946* (0.060)	0.926* (0.033)
R^2	0.99988	0.99988

Additionally, a fixed model where all three parameters of equation (1) were set constant was estimated. The fixed model can be considered as diffusion without disturbing factors. Why does the unrestricted model explain the observed diffusion so well? This is analyzed by comparing diffusion velocities between the fixed model and the observed diffusion, which are plotted in figure 2.

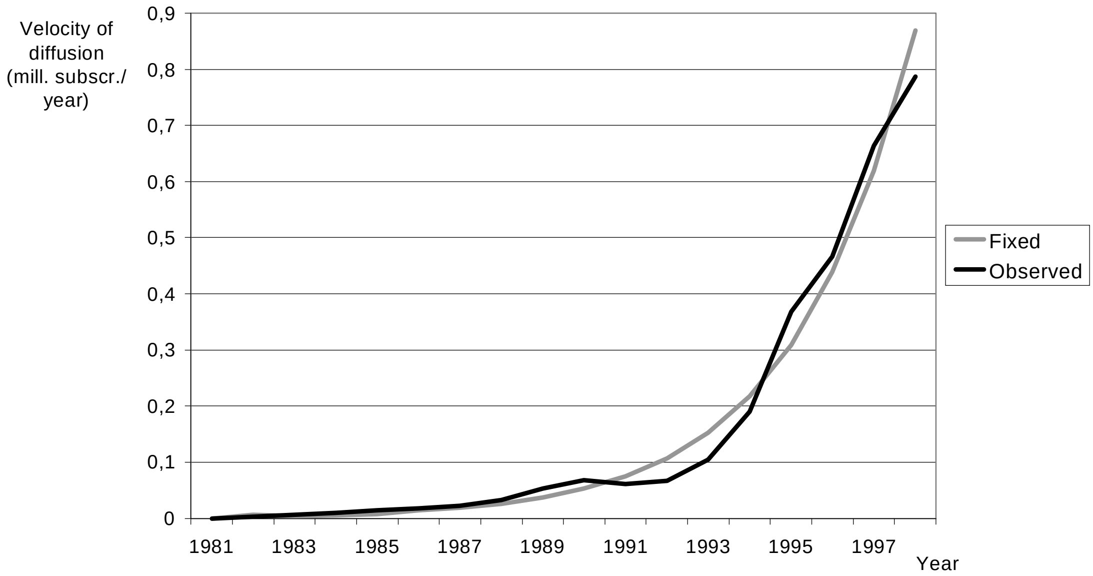

Figure 2. New mobile subscribers in 1981–1998. Actual observations and predictions of the fixed parameter model.

The following conclusions can be made by comparing the actual observations and the predictions of the fixed parameter model in figure 2. The fixed model overestimates the diffusion in the late 1980s, then underestimates the diffusion in the early 1990s, and again overestimates the diffusion in the mid-1990s. Explanations for this phenomena can be derived from the economic situation: Finland experienced an economic boom in the late 1980s and an economic recession in the early 1990s. If the fixed model is considered as diffusion under steady economic conditions, this could be interpreted as follows: In the economic boom of the late 1980s mobile communication was adopted earlier than it would have been under steady economic conditions. In contrast, the economic recession of the early 1990s delayed the adoption of mobile communication to the mid-1990s.

If the predictions of the unrestricted model are plotted against the actual diffusion, no great variations can be observed. This can also be read from the high explanatory power in table 1. Thus the economic situation has affected the diffusion of mobile communication.

The coefficient of the variable measuring the economic situation was estimated as 2.193. What can be concluded from the absolute value of this coefficient? Let's start by determining the measuring units of parameter *b* using the restricted model:

$$(6)\ b_t = \beta_a + \beta_b \cdot X_t^b \quad : \quad \frac{1}{\Delta t} = \frac{1}{\Delta t} + \frac{inhabit.}{mk \cdot \Delta t} \cdot \frac{mk}{inhabit.}.$$

Equation (6) shows, that the measuring unit of the coefficient is $(inhabit./mk \cdot \Delta t)$: thus, the coefficient is a parameter of the equation. The positive sign of the parameter denotes that the parameter is positively correlated with the relative growth rate: the better the economic situation, the greater the growth rate and vice versa. The absolute value can be interpreted by partial derivation: it tells how much a change of one unit in GDP per capita affects the relative growth rate. Gruber & Verboven (1999) estimate in their study of mobile communication service diffusion a coefficient of 1.533 for GDP per capita. This would indicate that the economic situation would have had a bigger effect on mobile communication's diffusion in Finland than in the EU. However, the model used by Gruber & Verboven (1999) is not analogous with the one used in this paper, and the currency unit appearing in equation (6) affects the comparison: if Finland's GDP per capita would be converted in euros, for example, the absolute value of the estimated coefficient would be different. This could have been solved by unifying the currency units, but Gruber & Verboven (1999) do not reveal their currency unit, which makes the comparison impossible.

The estimated coefficient of the potential adopters was 0.926. The final penetration rate can now be calculated by multiplying the coefficient with the percentage of population covered by the mobile network: $0.926 \times 0.99 = 0.917$. This means that mobile communication will finally diffuse among 91.7 % of the Finnish population; about 9 persons out of 10 will finally find themselves as mobile network subscribers.

4 FORECASTING THE DIFFUSION OF MOBILE COMMUNICATION

Forecasts of mobile communication's diffusion can be made by extrapolating the logistic model (equation 1) and using the parameter estimation results gained in chapter 3.

The future values of the used variables were gained by continuing the trend: GDP per capita is assumed to grow annually by a steady rate of 2.5 %, whereas the future population values are from Statistics Finland (1999). The mobile network coverage is assumed to remain at 99 %. The calculated predictions are not certain observations in the future, but they inhibit uncertainty, which is notified by calculating 95 % statistical confidence intervals. Because of the variance used for the confidence interval is calculated using a linear approximation of the estimated model the calculated confidence interval underestimates the actual 95 % statistical confidence interval. The predictions, the confidence intervals and the corresponding penetration rates of annual mobile subscribers in 1999–2010 are listed in table 2.[2]

Table 2. Forecasted diffusion of mobile communication. Predicted number of mobile subscribers and penetration rates in parentheses.

Year	1999	2000	2001	2002	2003	2004
Upper limit	3741889 (72,4 %)	4105943 (79,3 %)	4433562 (85,4 %)	4620891 (88,9 %)	4724291 (90,7 %)	4784721 (91,8 %)
Subscribers	3447139 (66,7 %)	3873693 (74,8 %)	4272952 (82,3 %)	4516161 (86,9 %)	4651888 (89,4 %)	4724344 (90,6 %)
Lower limit	3152389 (61,0 %)	3641443 (70,3 %)	4112342 (79,3 %)	4411431 (84,9 %)	4579485 (88,0 %)	4663967 (89,4 %)

Year	2005	2006	2007	2008	2009	2010
Upper limit	4822287 (92,3 %)	4845165 (92,7 %)	4860930 (92,8 %)	4873143 (93,0 %)	4883672 (93,0 %)	4893325 (93,1 %)
Subscribers	4762983 (91,2 %)	4783253 (91,5 %)	4795594 (91,6 %)	4804341 (91,6 %)	4811523 (91,7 %)	4817971 (91,7 %)
Lower limit	4703679 (90,1 %)	4721341 (90,3 %)	4730258 (90,3 %)	4735539 (90,3 %)	4739374 (90,3 %)	4742617 (90,2 %)

The prediction of 3.447 million mobile subscribers in 1999 could already be compared with the actual observation of 3.446 million. This minor deviation would indicate that the forecasted values of mobile subscribers are quite accurate. The final penetration rate of 91.7 % (some 4.82 million subscribers) is achieved already in 2009. By plotting the actual observations, the forecast and the confidence interval the S-shape of the diffusion of mobile communication can be seen (figure 3).

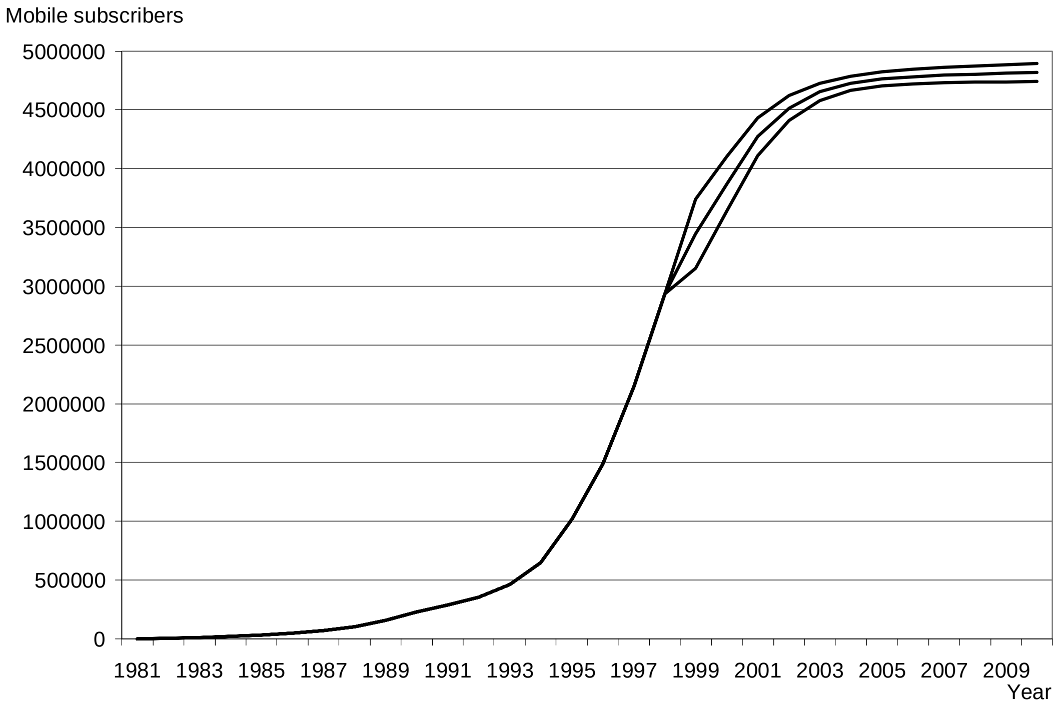

Figure 3. Actual, predicted and confidence interval for diffusion of mobile communication.

Gruber & Verboven (1999, p. 16) estimate the final penetration rate of mobile communication services in EU countries as 62 %. They consider their estimate as 'not unrealistic, though slightly higher than industry forecasts'. Finland passed this estimate already in 1999.

5 ANALYZING MOBILE COMMUNICATION'S DIFFUSION

As already seen in figure 2, taking the first derivative of equation (1) in respect to time gives the number of new subscribers in a time unit. An exact interpretation of this derivative is gained by dimensional analysis:

$$(7)\quad \frac{dy}{dt} \quad : \quad \frac{amount}{time}.$$

The dimension of formula (7) is *amount/time*, which is also the dimension of velocity. Thus, the first derivative in respect to time is the velocity of the diffusion process. Plotting the velocity of the observed and predicted diffusion of mobile communication gives figure 4.

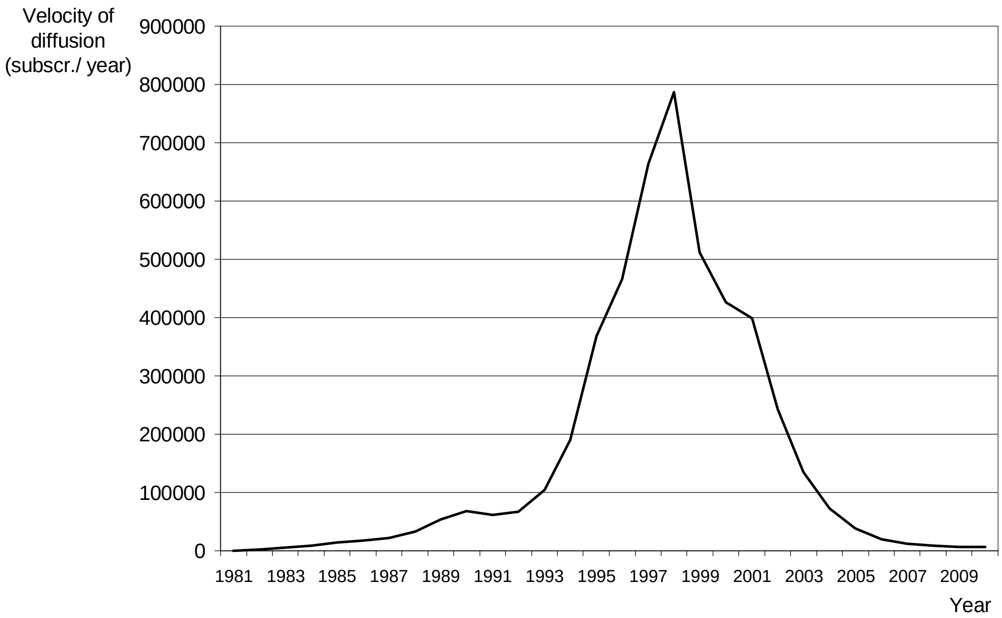

Figure 4. Mobile communication's velocity of diffusion.

Figure 4 shows that the maximum velocity of mobile communication was achieved in 1998: in this year mobile communication got the most new subscribers. Also, in the same year the S-shaped curve in figure 3 starts bending downwards. The 'pit' in the diffusion path caused by the economic downturn in the early 1990s comes out more clearly than by observing the whole diffusion path of figure 3. Let's continue by taking the second derivative of equation (1) in respect to time. The dimension of the second derivative is as follows:

$$(8)\quad \frac{d^2y}{dt^2} \quad : \quad \frac{amount}{(time)^2}.$$

The dimension of formula (8) is the same as the one of acceleration: *amount/*(*time*)^2. This shows that the second time derivative of the diffusion process measures the acceleration of diffusion; it indicates the change of the amount of new subscribers in a time period. The acceleration of mobile communication's diffusion is plotted in figure 5.

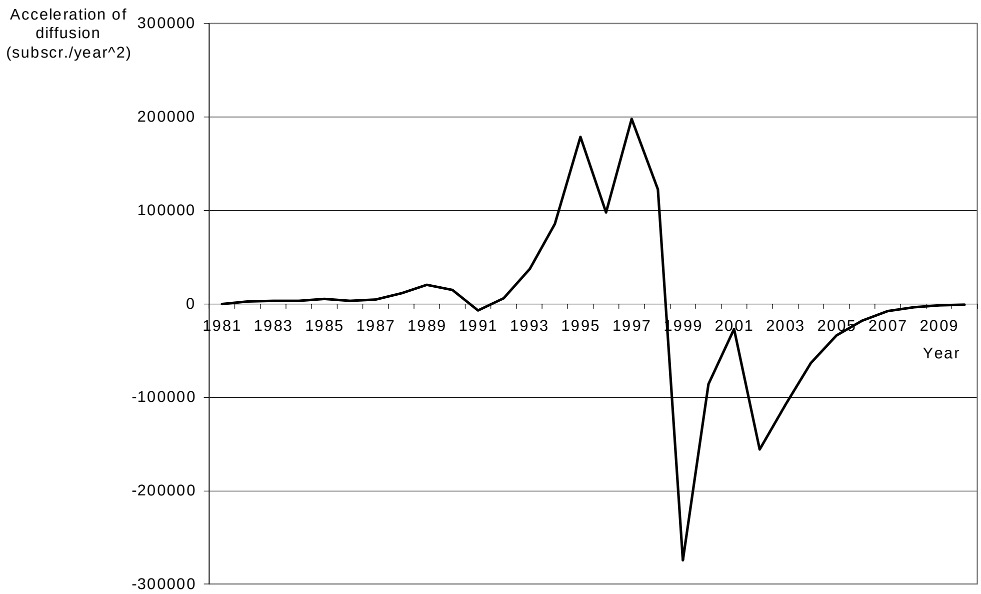

Figure 5. Mobile communication's acceleration of diffusion.

Figure 5 shows the acceleration of mobile communication's diffusion, which is the change in the amount of new subscribers. This figure shows the effect of the economic recession on the diffusion even clearer: acceleration is negative in 1991. This means that in 1991 mobile communication got less new subscribers than in 1990.

Let's divide the diffusion process into three phases by its extreme values: early phase, from the start to the maximum of diffusion's acceleration, phase of rapid growth from the maximum to the minimum, and phase of maturity afterwards. Now, figure 5 indicates that the diffusion of mobile communication achieved a local maximum in 1995 and a global maximum in 1997. The global minimum point of the diffusion is achieved in 1999, followed by a local minimum in 2002. Thus, the three phases took place in the following years: early phase in 1981–1997, rapid growth in 1997–1999, and maturity from 1999 onwards. Additionally, using the local extreme values, a wider phase of rapid growth can be determined as 1995–2002.

Rogers (1995, pp. 261–266) categorizes adopters of an innovation into innovators, early minority, early majority, late majority and laggards. Innovators form the first 2.5 % of the adopter population, early minority the next 13.5 %, early majority the next 34 %, late majority the next 34 % and the remaining 16 % are laggards.

As the final number of mobile subscribers in Finland was estimated as some 4.85 million, the categories' points of time can now be calculated. Innovators were the first 121 250 adopters, which was passed in 1989. The adopters 121 251-776 000 belong to the early minority. These adopters became mobile subscribers in 1989–1995. The early majority consists of those who adopted before 2.425 million mobile communication subscribers existed – this figure was passed in 1998. The subscriber numbers 2.425–4.074 million, that is in 1998–2000, form the late majority. The remaining adopters, i.e. those who adopt after 2000, can count themselves as laggards. In 1993 the subscribers of mobile communication were distributed as follows: enterprises and persons engaged in professions formed 82 % of mobile communication subscribers, households 14 % and public sector 4 %. This would mean that the innovators and early majority were mainly formed by enterprises and persons engaged in professions. (MINTC 1994, figure 1.38, p. 36)

The results of the two methods used for categorization are quite similar: According to the wider phase of rapid growth, the early phase ended in 1995, which corresponds with the year when early majority had adopted. The phase of maturity began in 1999, which is close to the date of the late majority's adoption in 2000.

6 CONCLUSIONS

This paper studied the diffusion of mobile communication in Finland. The objectives were 1) to find factors, which have affected the diffusion process, and 2) to forecast the diffusion process. Observations of mobile subscribers in NMT and GSM standards were used as data for studying the diffusion of mobile communication.

Based on the epidemic theory of innovation diffusion, the data was fitted in a logistic model by means of non-linear least squares. Factors affecting the diffusion process were studied by writing two parameters of the logistic equation as functions of variables. The results for the first objective were that the economic situation has affected the relative growth rate of the diffusion process, and that the number of potential adopters has been a constant fraction of the population covered by the mobile network. Additionally, the final penetration rate was calculated as 91.7 %. Considering mobile communication's observed penetration of 66.7 % in 1999, this estimate seems certainly more realistic than the penetration of 62 % on the EU level estimated by Gruber & Verboven (1999). The second objective was studied by extrapolating the estimated model until 2010, which resulted in annual predictions of mobile communication subscribers. The uncertainty of these predictions was taken into account by calculating a statistical confidence interval using the estimated model's linear approximation.

For analyzing purposes, the first and second time derivatives of the diffusion process were determined respectively as the velocity and acceleration of the diffusion process. Analyzing the velocity and acceleration helped understanding the diffusion process of mobile communication. The acceleration of diffusion was divided into phases: early, rapid growth and maturity. Comparing these phases to Rogers (1995) adopter categorization resulted in similarities.

Future work could, for example, test the model used in this paper with other countries' mobile communication data. The preciseness of the predictions made in this paper will be shown by future observations. However, an analogous study after a few years have passed, and more observations are available, would indicate how well this study succeeded in modeling the diffusion process. Finally, the diffusions' velocity and acceleration as analyzing tools could be developed further and used with other innovations.

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[1] All time series used were co-integrated.

[2] Predicting 12 observations with a model based on only 18 observations is not reliable. The aim, however, was to find out the year of final penetration, and to show the S-shape of the diffusion process.

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