A SPATIAL MODEL OF THE DIFFUSION OF MOBILE COMMUNICATIONS WITHIN THE EUROPEAN UNION

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ABSTRACT

Innovation diffusion studies have been popular. However, usually the focus has been on two dimensions: Either the innovation's diffusion is studied on the micro level by examining the individual's adoption of an innovation, or on the macro-level by modelling the sigmoid diffusion curve. The third dimension of the diffusion of an innovation, spatial diffusion, has gained less attention.

In this study, a gravity-based model is employed for studying the spatial diffusion of mobile communications within the European Union. The model considers the diffusion process on a national level, the adoption units being the member countries of the European Union. The amount of spatial interaction, or gravity, is calculated to measure the interaction between the innovation center, Sweden, and other countries. The adoption year of the countries are then estimated by using their amounts of interaction. The results indicate that the adoption timing of a country is related to its amount of interaction with the innovation center country. However, because of two outlier countries, the model does not give ideal results.

1 INNOVATION DIFFUSION RESEARCH

The research of the diffusion of an innovation has been seen as a rewarding research subject: If the diffusion process of an innovation can be successfully modelled, i.e. if the factors affecting the diffusion process of an innovation can be revealed, the forecasting of the innovation's future diffusion is enabled. Usually the diffusion process is assumed as being deterministic, and no stochastic components are included in the models, although some exceptions exist. The interest has focused on products and factors affecting the diffusion of these. For example, a greater visibility of a product has been seen as facilitating its diffusion process. On the other hand, also environmental macro-level variables have been found as affecting the diffusion process. If the factors affecting a product's diffusion process could be determined, a sales forecast for the product based on the predictions of the development of the affecting variables could be made. Moreover, if the variables affecting the diffusion process are such that they could be adjusted, also the whole diffusion process of the product may be controlled. Thus, the definition of the factors affecting a product's diffusion process helps the planning process of a products marketing.

The mainstream theory of innovation diffusion sees the spread of information as the main factor behind an innovation's diffusion process: Because information spreads following a sigmoid (s-shaped) curve, also the innovation spreads following this pattern. Thus, an innovation is seen to spread first slowly, then rapidly and in the end again slowly into the adopting population. Despite the simple, and might even banal information-spread based theory behind the diffusion of an innovation, empirical data often reveals this S-shaped pattern.

The majority of innovation diffusion research concentrates on modelling this sigmoid diffusion process of an innovation, and it may be classified as macro-level innovation diffusion research. The macro-level, the aggregate of individual adoptions over time, started by studies of Ryan and Gross (1943), and subsequently e.g. Griliches (1962) and Bass (1969) contributed in the field by introducing a mathematical model for modelling the diffusion process. Another great research focus has been studying and modelling the adoption process (the diffusion on the micro-level) of an innovation. The adoption process of an innovation has been studied e.g. by Rogers (1995).

The third dimension of an innovation's diffusion, the spatial level, has gained less interest from researchers. However, the diffusion of an innovation takes place simultaneously in time and space (Mahajan, et al., 1990; Mahajan and Peterson, 1979), but previous research has concentrated mainly on the time dimension, even though the seminal work on spatial diffusion was done by Hägerstrand already in 1967. The lack of spatial diffusion studies may be due the lack of spatial data of innovations' adoption; often the data used in spatial diffusion research has to be simulated. If the spatial diffusion of an innovation could be understood and modelled, it would enable spatial forecasts of an innovation's spread.

However, there exist some spatial studies of the differences of an innovation's diffusion between a set of countries, but only a few study or try to model the process of spatial diffusion. Recently, mobile communications has been a quite popular innovation to be studied: The diffusion has been investigated on a nation-level (Wright et al., 1997 and Frank, 2000), on a multi-nation level (Gruber and Verboven 2001; Gruber 2001), and on a worldwide level (Dekimpe et al. 1996).

The aim of this paper is to model the spatial diffusion of mobile communications in the European Union. More specifically, the aim is to investigate, whether a spatial gravity model can be utilized for modelling the European Union member countries' adoption years of mobile communications. The next section introduces to the background of the diffusion of mobile communications in the European Union, where after the concept of spatial diffusion and the gravity model is introduced. The fourth section presents the results of the empirical analysis. Finally, the last section discusses the results of this paper, provides conclusions and suggests further research topics.

2 MOBILE COMMUNICATIONS IN THE EUROPEAN UNION

By the information of mobile subscribers provided by the EMC database, Sweden was the first to adopt mobile communications of the European Union member countries in

1981. Finland and Denmark were the first to join Sweden in the next year, and the majority of the EU countries followed Sweden after 4 years. However, Portugal adopted 8 only years after Sweden, and from Greece it took 12 years to adopt mobile communications. This adoption timing of the EU countries is summarized in table 1.

Table 1. Year of adoption in the EU countries.

NAME	AUT	BEL	DNK	FIN	FRA	DEU	GRC	IRL	ITA	LUX	NLD	PRT	ESP	SWE	GBR
YEAR	1985	1987	1982	1982	1985	1985	1993	1986	1985	1985	1985	1989	1982	1981	1985

The following maps in figure 1 illustrates the subsequent diffusion of mobile communications in the member countries. The maps show the penetrations of individual countries, and also the differences between countries' adoptions and penetrations.

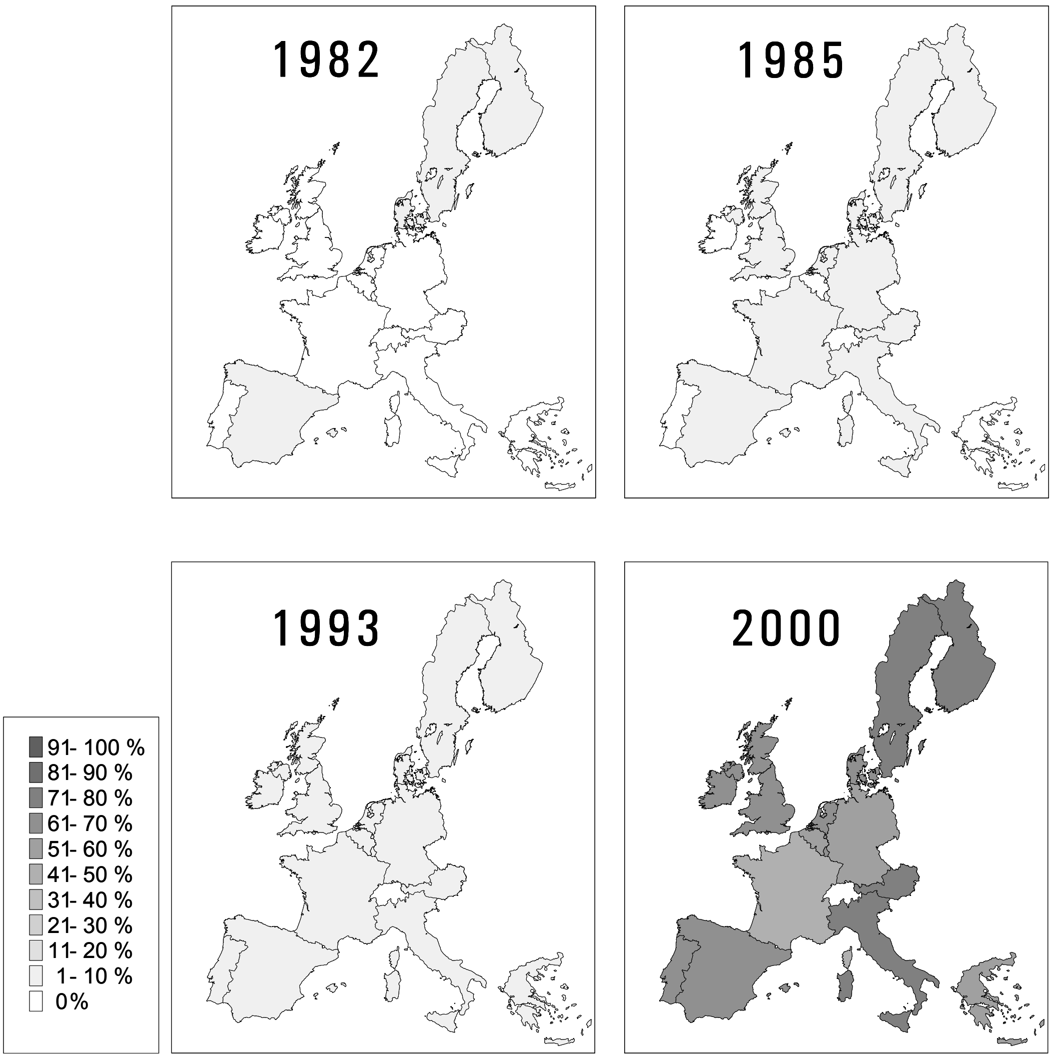

Figure 2. Penetration rates of mobile communications in the European Union member countries in years 1982, 1985, 1993 and 2000.

The maps in figure 1 show a higher penetration by a darker color. As figure 1 shows, in 1985 mobile communications was adopted in the majority of EU countries, but its penetration rate was still low. By this time, only Belgium, Greece, Ireland and Portugal had not yet adopted mobile communications. In 1993, all of the EU countries had adopted mobile communications. After that, the penetration rates started to grow quickly, in year 2000 the market was already close to saturation. One factor causing the rapid growth might have been the introduction of a common digital standard, the GSM (Global System for Mobile Communications) standard in 1992.

The actual diffusion also shown by the maps in figure 1 may also be illustrated by diffusion curves. The currently available data of annual mobile communications ranges to year 2001. By plotting the annual penetration rates against time, the diffusion curves of individual countries may be depicted. Figure 2 illustrates the diffusion curves of mobile communications, by individual countries and on the aggregate EU level.

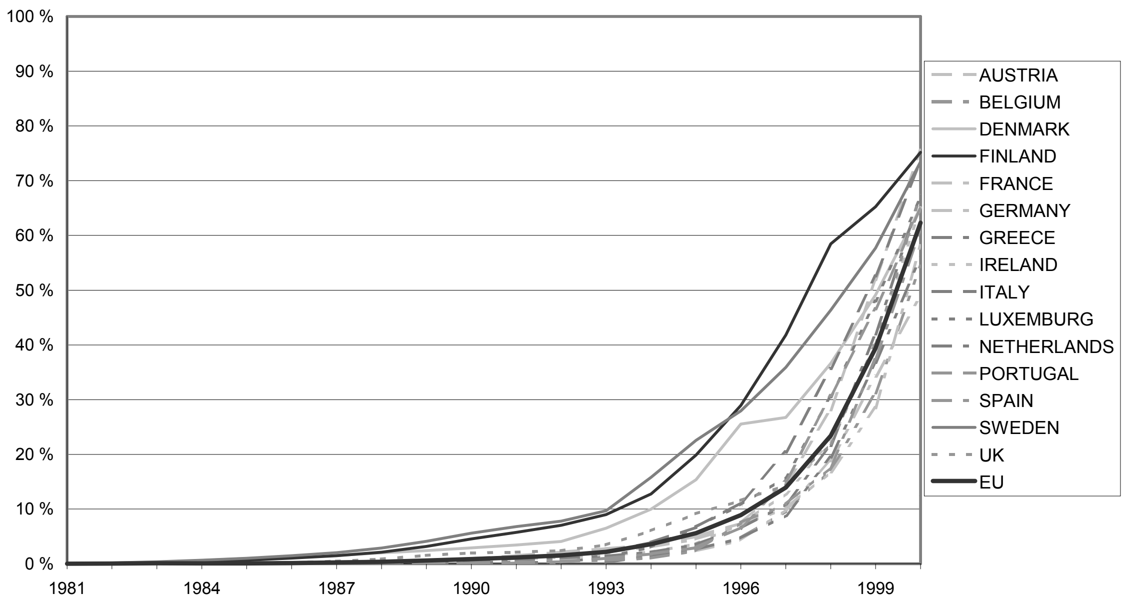

Figure 2. The diffusion of mobile communications in the EU member countries.

Although it is hard to separate individual countries' diffusion paths in figure 2, it seems that Finland, Denmark and Sweden have taken a path different from the other countries: The former have adopted mobile communications earlier (see table 1), i.e. they can be considered as first-movers, and have had a clear margin to the other countries, which seem to be quite much clustered together. This might be due to the common standard of the Nordic countries (NMT, Nordic Mobile Telephone). However, lately the margin of the three first-movers has diminished as the other countries have caught them. Recently, Austria overtook the first-movers, and now has the highest penetration rate.

3 SPATIAL DIFFUSION AND THE GRAVITATION ANALOGY

When modelling the diffusion of an innovation at the macro-level, usually a S-shaped function is used as the basis for the diffusion equation. For example, the logistic function is very popular for this purpose (see e.g. Frank 2000; Gruber & Verboven 2001). These diffusion equations have two kinds of parameters: One measuring the upper asymptote of the curve, i.e. the eventual level or penetration of innovation's diffusion, and one measuring the slope of the diffusion curve. A third parameter defines the timing of the diffusion, but it is only of use in cross-country comparisons. These two parameters, the upper asymptote and the slope, are subsequently written as functions of hypothesized affecting variables. The hypothesized effects are then usually tested employing non-linear regression analysis (since the diffusion function is of non-linear form), which indicates the significance and magnitude of the effect as a result.

Hagerstrand (1967) pioneered in spatial innovation diffusion studies. He divided the spatial diffusion of an innovation into two effects: a neighbourhood effect and a hierarchical effect. The neighbourhood effect hypothesizes that places closer to the innovation center (the place of the innovation's origin), in terms of geographical distance, adopt earlier. Places of similar distance thus experience a similar diffusion process. The hierarchical effect postulates that places closer to the innovation center's hierarchy, measured e.g. by population size, adopt earlier. Also, places of similar hierarchy have a similar diffusion process.

Some spatial diffusion models build solely on the effect of distance on an innovation's diffusion process. Generally, it is seen that the innovations diffusion comes behind in places further away from the innovation centre. Such a model was created e.g. by Mahajan and Peterson (1979) who studied the diffusion of tractors in the United States by studying separately diffusion within 25 U.S. states. They applied modified Bass model, which captures both the time and space dimensions. Formally, their method to model spatial diffusion has been as follows: The location of the place has been tested to affect the location's penetration value (the upper asymptote of the S-curve), the hypothesis being that the further the place from the origin of the innovation, the lower the acceptance. This phenomenon is also been referred to as a "travelling wave" (see Karmeshu and Puri 1998), since if depicted on a distance-penetration graph it looks like a wave on its way from left to right. Mahajan and Peterson (1979) postulated the existence of a neighbourhood effect in their study, i.e. the smaller the geographic distance the larger the cross-region influence, as they found that the rate of substitution decreases with the distance from the innovative region (i.e. the innovation center of the country).

Some additional studies have only examined the diffusion processes of different countries by comparing their scores in some spatial variables, such as mobility (Gatignon et al. 1989) and distance from the innovation center (Frank 2001). The lack of spatially oriented diffusion studies comes probably from the fact that innovation diffusion data with attached spatial information is not easy to collect.

Another approach for studying the spatial diffusion of an innovation is the spatial gravity model. It measures the interaction between places, which further can be thought of as positively affecting the diffusion of an innovation: The more interaction between the innovation center and a given place, the earlier the innovation is adopted in the place. As the name of the spatial gravity model implies, the diffusion caused in it because of different pulling forces of regions. In other words, regions adopt the innovation at a different time because of a different pulling force. The spatial gravity model can be formalized as follows (see e.g. Morrill et al., 1988):

$$(1)\ V_{ij} = K \frac{P_i^{a_i} P_j^{a_j}}{\exp\left(-b \cdot D_{ij}\right)}.$$

In formula (1), V_{ij} stands for interaction between two places, i and j. P_i is the population of place i and P_j the population of place j. As can be read from the equation, the interaction is directly proportional to the product of the populations of the two locations. The denominator in the right hand side of formula (1) states that the interaction is inversely proportional to the distance separating the two places D_{ij}, the effect of distance having a negative exponential decline. Additionally, *K* is a constant of proportionality, the two *a*s index the relative importance of the origin and destination locations, and *b* is the rate of distance decay. Thus, the equation states that the chance of interaction of people living in these two places decreases as the distance separating the two places increases, and the interaction increases as the number of residents of the locations increase.

For the study of the spread of an innovation, formula (1) may be simplified. This is because the diffusion of an innovation has a place of origin, a place where it is adopted first. This place is also referred to as the innovation center. Because of the other location is given, only the interaction between the innovation center and other places needs to be studied. As a result, parameters *K* and a_i are unimportant and the equation reduces to:

$$(2)\quad V_{ij} = \frac{P_i P_j^{a_j}}{\exp\left(-b \cdot D_{ij}\right)}.$$

Now, using the terms of Hagerstrand (1967) the diffusion process is solely due to effect of distance (neighborhood diffusion) if $a_j = 0$ and $b > 0$. If $a_j > 0$ and $b = 0$, the diffusion process is affected solely by the population of the places and thus the diffusion is of hierarchical type. If both of the parameters are zero, the diffusion is random, which is a rare phenomenon.

4 A GRAVITY MODEL OF THE ADOPTION OF MOBILE COMMUNICATIONS IN THE EUROPEAN UNION

From above we recall that Sweden can be considered as the innovation center of mobile communications, as it was the first European Union member country to adopt mobile communications. Supposing this, the interaction given by the gravity model is calculated between Sweden and the other countries. The distances used in the gravity model are the absolute distances of the capital of Sweden, Stockholm, and of the other countries' capitals. The populations used in the nominator are those of the member countries, measured in the beginning of the diffusion. A distance decay (parameter *b*) of 0,001 was used to scale the absolute distance, in order to get the exponential function calculable. Also, to weight the populations significance, a power of $a_j = 0.1$ was used. The distances, populations and the rates of interaction presented in table 2 were the results from these calculations.

Table 2. The distances (km), the populations (in millions) and the interaction rates between Sweden and the other EU countries.

NAME	AUT	BEL	DNK	FIN	FRA	DEU	GRC	IRL	ITA	LUX	NLD	PRT	ESP	SWE	GBR
KM	1247	1284	526	396	1549	1187	2410	1625	1984	1325	1132	2993	2596	0	1436
POP	7,6	10,0	5,1	4,8	55,3	59,5	10,4	3,4	56,7	0,4	14,5	9,9	8,4	37,6	57,0
RATE	1,40	1,39	2,77	3,13	1,26	1,83	0,45	0,89	0,82	0,96	1,68	0,25	-	0,43	1,42

From table 2 we can note that countries physically close to Sweden have gained the greatest interaction rates. Also, we may observe that the most distant countries have the smallest interaction rates. Figure 3 presents scatter-plots of gravity, or the interaction rate, with respect to the physical distance and population.

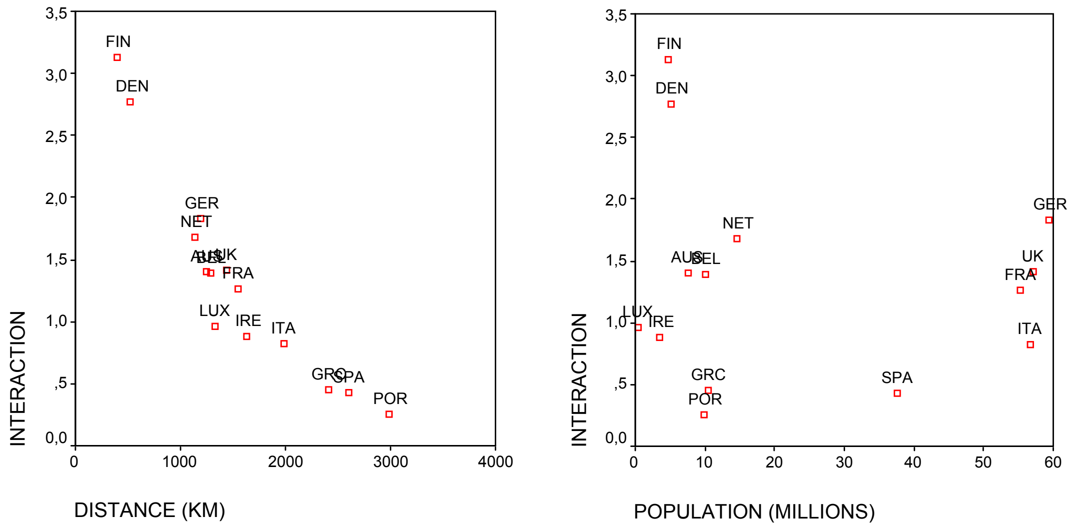

Figure 3. The relationships of interaction, physical distance and population.

Theoretically, a country should adopt an innovation earlier, if it has more interaction with the innovation center. To see whether such a relationship exists, the spatial interaction values are plotted against the actual adoption years (see table 1) of the countries in figure 4.

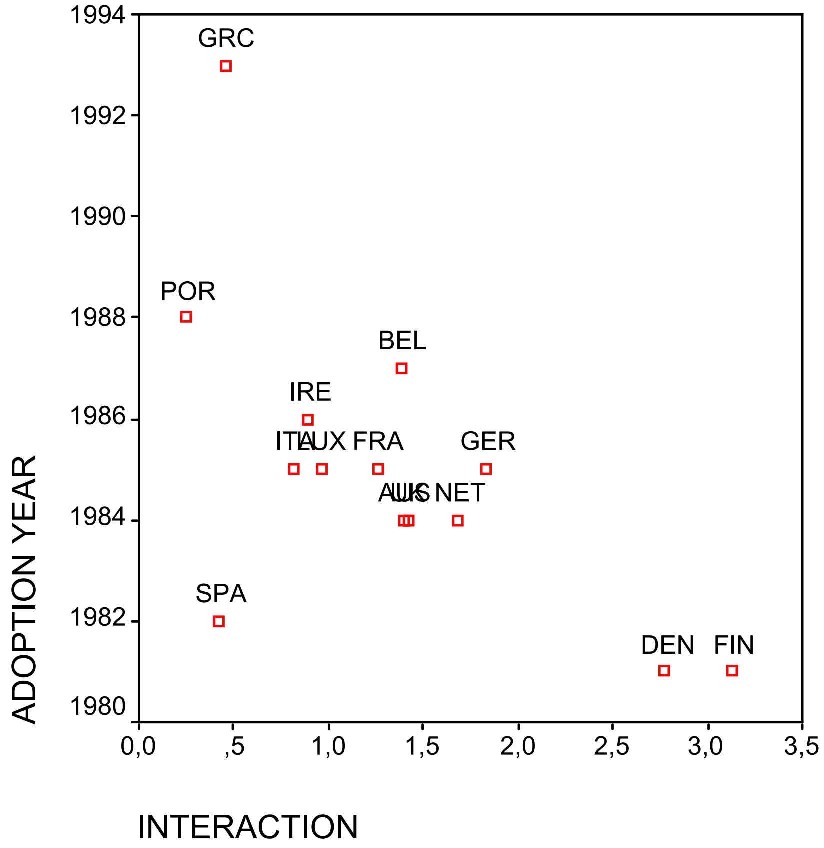

Figure 4. Gravity and the adoption year of the EU member countries.

As figure 4 shows, the spatial interaction (or gravity) appears to decline somewhat linearly with the increase in the years of adoption. Only Spain and Greece seem to be exceptions of this trend: By the estimated amount of interaction with the innovation center, Spain has adopted "too early" and Greece "too late". Despite this, a linear equation is used to explain the adoption year by the spatial interaction:

(3) $YEAR_i = a + b \cdot GRAVITY_i$.

The results of formula (3) are a = 1988.145 (p = 0.000) b = -2.357 (p = 0.013) and R^2 = 0.413. However, if the two outlier countries, Spain and Greece, are excluded from the regression, the results are markedly better: a = 1987.940 (p = 0.000) b = -2.263 (p = 0.000) and R^2 = 0.786. Thus, only the amount of interaction with the innovation center does not effectively explain the member countries' adoption timing of mobile communications.

5 CONCLUSIONS

In this study, the diffusion of mobile communications in the European Union was modelled by employing a spatial gravity model. The analysis showed that the adoption of mobile communications in the European Union might be modelled using the gravitation analogy. Clearly, there exists a tendency of distant countries being later adopters. Also, the size of the country, measured by its population, seems to affect its adoption year positively. Based on the spatial interaction between the innovation center and the adopting country, the estimated model performs quite well in predicting the adoption years of the member countries. However, the model does not produce perfect results mainly because of two outlier countries, Spain and Greece. The exceptionalities of these countries might be taken into account by the regression equation with the inclusion of additional variables. Such a variable could measure e.g. the fact that Greece did not have a tradition in mobile communications before the digital GSM system, and thus correct the bias.

Spatial innovation diffusion research basically examines the effect of location on the innovation's diffusion process. Traditionally, the effect of the location of a given place on its diffusion process has been taken into account by incorporating the location parameters into a macro-level diffusion model. However, the spatial diffusion of an innovation might also be examined as well on the micro-level: How does the location of an adopter affect his adoption decision of an innovation?

This study showed that the spatial gravity model might be employed for modelling and predicting the adoption time of a country. Previous diffusion studies have shown that the diffusion of a country can be modelled by some sigmoid shaped curve. Further research could try to integrate these two models together, so that the combined model could predict the adoption time of a location by using the gravity model, and the subsequent diffusion by means of, for example, the logistic model.

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