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Online social networks, location, and the dual effect of distance from the centre

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Abstract

Online social networks (OSN) are major platforms of ICT-enabled communication, supporting place-independent social life. However, recent findings suggest that the geographical location of users strongly affects network topology. Therefore, OSNs may be simultaneously related to locations and also unlocked from offline geographies. Our paper addresses this dual-faced phenomenon, analysing the location-specific effect on OSN diffusion and OSN usage. Findings on iWiW, the leading OSN in Hungary in the 2000s with more than 4 million users, suggest that the rate of users (proxy for OSN diffusion) is positively associated with the geographical proximity of Budapest, the foremost urban centre in the country. On the contrary, the average number of connections (proxy for OSN usage) is independent of the geographical proximity of the capital, and it is even higher in peripheral regions when controlling for other offline factors.

Introduction

The majority of geography-oriented research on online social networks (OSNs) is based on a body of literature in which major concepts and “placeless” hypotheses were formulated in the 1990s due to the revolutionary development of the internet (Cairncross 1997). Cyberspace quickly became a central issue in understanding human behaviour in the virtual world, and the cyber world has always been claimed to strongly intertwine with the physical world (Batty 1993, Hayes 1997). More recently, the concept of cyberplace has been used to depict internet-mediated communication, underlying the importance of spatial base and the diminishing role of distance in internet infrastructure (Devriendt *et al*. 2008, Tranos and Nijkamp 2012). However, further efforts are needed to unveil the spatial dimension of the offline-online interrelatedness, and OSNs provide excellent data sources for analysing this issue. In this paper, we compare the role of location-specific factors and the distance from the centre in OSN diffusion to the role of the same factors in OSN usage.

OSNs are large-scale networks built in social network sites that are major fields of online communication and that "*enable users to articulate and make visible their social networks*" (boyd and Ellison 2007, at p. 212.). Thus, OSNs are claimed to be supplemental forms of communication between people who have primarily known one another in real life (Ellison *et al*. 2006, 2007). These websites not only speed up local communication but also empower people to connect themselves to distant friends (Backstrom *et al*. 2011). It has been shown that geography is a determining factor in OSNs; the location of users and their friends strongly influences the topology of the network, and most social ties remain within geographical boundaries (Takhteyev *et al*. 2012, Ugander *et al*. 2011). However, the role of geographical factors in OSN diffusion and OSN usage is under-researched.

One may associate the diffusion of a particular OSN with innovation spread because joining an OSN is, after all, an adaptation to new communication trends. Diffusion has always been closely related to spatial patterns (Griliches 1957, Hägerstrand 1967), and location-specific characteristics have remained crucial for innovation diffusion even after the internet has reduced communication costs (Feldman 2002). Because face-to-face interactions have not lost their importance in knowledge sharing, we propose that geographical proximity favours and geographical distance decays diffusion.

However, the role of geographical location and distance is not at all clear regarding OSN usage. The internet seems to stimulate local offline communication (Storper and Venables 2004). Users primarily interact with their strongly connected cliques but are also able to extend their interactions to more distant places than ever before (Wellman 2002). For example, communication on certain online platforms might be centred on short messaging to massive communities that are primarily local (e.g., Facebook), whereas others are principally designed to communicate with distant friends (e.g., Skype; Lobburi 2012). Therefore, involvement in online communities might be very similar across agents scattered in space regardless of geographical location and distance from the centre. One might even suppose that distance intensifies online activities because of cost concerns.

The paper is based on a dataset collected from iWiW, the leading Hungarian online social network in the 2000s with more than 4 million users, and focuses on two questions. First, how does the geographical distance from the centre affect the rate of users in the total population, which is the proxy for OSN diffusion? Second, how does the geographical distance from the centre affect the average number of friends (which we apply as a proxy for location-specific OSN usage)? Findings suggest that the OSN has diffused more easily into settlements that were geographically proximate to Budapest, the capital of the country where iWiW was launched. However, the average number of friends in the OSN seems to be independent of the geographical distance from the centre; this indicator even becomes significantly higher in peripheral regions far from the capital when controlling for other offline factors.

The contribution of the paper is twofold. First, we illustrate the effect of geographical location on the OSN using "population" type settlement-level data, such as population, economic development, telecommunication usage, and settlement structure. Second, we demonstrate that distance from the centre has an adverse effect on the OSN user rate among the total population and on the average number of online connections. Thus, distance might have a dual role in OSN geography and retard the diffusion of joining the network while simultaneously increasing the intensity of OSN usage in peripheral places.

Location, distance, and internet: an overview

The revolutionary development of the internet and other forms of digital communication sounded the alarm for geographers to reformulate major concepts and hypotheses in the 1990s. Cyberspace became a central issue in understanding human behaviour in the virtual world, while the term cyberplace is used to depict spatially grounded online activities (Hayes 1997, Wellman 2001). The diminishing role of geography was envisaged in the "death of distance" theorem of Cairncross (1997). However, empirical evidence has repeatedly shown that physical place and distance have a determining power in online communities (Liben-Nowell *et al*. 2005) and internet infrastructure (D'Ignazio and Giovanetti 2007, Tranos and Nijkamp 2012).

The character of cyberspace is various and complex. It could be characterised as some type of conceptual space for the flow of information that came to existence through the elemental combination of the digital world's hardware materiality, the software of computers, telecommunication networks, and the human mind (Devriendt *et al*. 2008). Cyberspace is neither technology nor infrastructure; rather, it is a medium for the complex convergence of computers, communication and people (Dodge 2001). The space of flows – which Castells (1996) refers to as cyberspace – is fluid and offers wide possibilities for everyone, and it may become independent of real physical space (Kitchin 1998).

Cyberplace is central element of virtual geography and is defined as the projection of cyberspace onto real space (Batty 1997). Cyberplace is something between physical and cyber space; on the one hand, it is a composition of the internet infrastructure, fibres and satellite networks, and on the other hand, it is the technological elements of data communication, which are all embedded in real space (Tranos 2011).

Modern interpretations of geography determine cyberspace and cyberplace to be either similar or radically different from traditional geographical spaces; however, the ties between these concepts can be naturally found (Wellman 2001). Due to the appearance and widespread use of internet technologies, the geographical consequences of changes necessarily became a topic to be analysed. Research outcomes of conceptual and empirical analyses were, however, varied regarding the effects of the internet on recent geography. In connection with the seemingly immediate appearance of ICT's communication possibilities, particularly in connection with internet technologies, researchers often predicted the radical compress of space-time relations, which could result in the complete "destruction" of space through time (Atkinson 1998, Brunn and Leinbach 1991, Cairncross 1997, Morgan 2001). In certain compositions, this has led to a feeling that the new digital and globalised world is similar to a pinhead or at least to its "sense" (Negroponte 1995), and geographical location is not relevant for it.

In contrast, with radical standpoints, it is becoming more accepted that although the internet and cyberspace have essential corrective effects on time-space relations, geographical aspects have important roles henceforward in many ways. If we postulated social sciences' terms of external space, the ones that should be taken into consideration, which had the momentum of definite localisation. Geolocation could be determined to be a linkage between spatial units, cities, regions or the spatial delineation of material objects (e.g., fibre networks) with known geographical positions. All the formations that could be identified along these cross-sections are possible to be visualised in physical space and herewith form the traditional space of information geography (Haklay *et al*. 2008). As with many social phenomena, in the information society, we can also often stumble upon social components with a system of connections or relations to one another that show independent spatial characteristics. The mentioned interior spaces cannot be geographically localised at all (Sucháček 2004, Fabrikant 2000).

However, scholars also warn us that geographical location is still a major factor that shapes the internet layer of human life. For example, Brian Hayes (1997) argues that the internet cannot exist independently of conventional geography because no bit can proceed via the net without passing through kilometres of wires and optical fibres or tons of computer hardware, which are all in physical space indeed. Furthermore, Tranos and Nijkamp (2012) argue that although the internet has lowered the costs of communication, establishing a link to distant places has higher costs than does linking to proximate places. Thus, physical distance has a diminishing effect on the internet's infrastructure.

Studies on online communities highlight that similarly to the virtual world-physical world interrelatedness (Benedikt 1991), internet communities are spatially and socially based (Jones 1995). Online communities are constructs of cultural, structural, political, and economic character, which are based on geographically bound social relations and institutions (Fernback 2007). Thus, "glocalisation" is a major phenomenon in internet-based communication; due to the internet, people have stronger interactions in their local area and extend some of their interactions to the global level (Wellman 2002). Consequently, distance plays a major role in online community construction. As the distance between two random individuals increases, their probability of belonging to the same online community decreases.

Location, distance, and online social networks

To address the importance of geographical location and distance in the diffusion of online social networks and the average number of friends, we first need to go through the geo-location specialities of OSNs. There has been a growing scientific interest in recent years in analysing OSNs; mainstream research covers a wide area, including learning and communication processes (Greenhow 2011), online identity (Zhao *et al.* 2008), youth and digital media (boyd 2008), online privacy (Acquisti and Gross 2009), and network dynamics (Kumar *et al.* 2006), among others. Geography has also been involved in the discussion, primarily in the field of user-generated information mapping (Yardi and boyd 2010).

OSNs are large-scale networks on social network sites (SNS) in which users are the nodes and their connections with other users are the edges. SNSs are defined as web-based services that "*enable users to articulate and make visible their social networks*" (boyd and Ellison 2007, at p. 212.). The definition claims that SNSs are supplemental forms of communication between people who have known one another primarily in real life (Ellison *et al*. 2006, 2007). In other words, major SNSs are not used to meet new people but rather to articulate relationships with people in their existing offline network. Furthermore, the degree distribution of Facebook is very close to the degree distribution of real-life social networks (Ahn *et al.* 2007, Backstrom *et al*. 2011, Ugander *et al*. 2011). In other words, OSNs clearly differ from other web-based networks, such as internet infrastructure. The latter are led by power-law tie-distribution: A small share of webpages accounts for an outstandingly high number of links (Barabási and Albert 1999). In our understanding, OSNs are "biased versions of real-life networks" (Backstrom *et al*. 2011, Ugander *et al*. 2011).

Therefore, when we claim that virtual space provided in SNSs and the physical world are strongly interrelated, we assume that flesh and blood users document their offline friendships in the online environment. The geo-location of online content is based on the position of users that can stem from voluntary geographic information that users attach to the content they upload (e.g., pictures) or can be based on IP addresses (Elwood *et al.* 2012). The possible projection of the virtual world onto real geographies and the effect of location on shaping cyberplaces poses several questions that are beyond the scope of this paper. For example, research is still missing on the correlation between online and offline social networks (Traud *et al.* 2008, Hogan 2009). We only gather that geographical location and the physical distance from the central location are very important in OSNs. Other geography-related papers discussed this topic, mentioning basic outcomes in relation to OSNs, as follows.

First, spatial dimension and geographical location seem to determine OSN ego networks. Liben-Nowell and his colleagues (2005) highlighted that only one-third of friendships established on LiveJournal was independent of bound geographical areas. Escher (2007) also found that the majority of ego networks are local. Takhteyev et al. (2012) demonstrated that the majority of social ties on Twitter are within city agglomerations. A mega-analysis of Facebook found that the majority of connections are within country borders and the number of ties across countries accords with geographical distance (Ugander *et al.* 2011). Thus, the geographical location of the user strongly determines the geographical position of the friendship ties she documents on the website.

Second, distance seems to be of crucial importance in OSNs. In general, tie formation in social networks is deflated by the geographical distance between two locations due to travel-related and communication costs (Borgatti *et al.* 2009, Expert *et al.* 2011). Although spatial effects do not solely determine social group formation (Daraganova *et al.* 2012, Onnela *et al.* 2011), the probability of online friendship decreases as distance grows (Liben-Nowell *et al.* 2005, Scellato *et al.* 2010). Takhteyev et al. (2012) showed that this probability is influenced by various other factors, such as national borders, language differences and travel frequencies. The authors found that the frequency of airlines between two cities has the strongest correlation with inter-city Twitter ties. Additionally, information flow on Twitter is related to offline space, and distance has a major deterring power over it (Crampton *et al.* 2013, Yardi and boyd 2010). Finally, a study on the global Facebook network found evidence of a “small world phenomenon” (Backstrom *et al.* 2011) that accords with our geography focus. Users formulate strongly connected cliques with physically proximate other users, whereas relatively few long-distance ties connect the entire network and establish short average paths between two random users.

Our paper aims to contribute to the above literature in two aspects. First, we illustrate the effect of geographical location on OSNs using "population" type settlement-level data, such as population, economic development, telecommunication usage, and settlement structure. Second, we will demonstrate that the distance from the centre has an adverse effect on OSN user rates among the total population and on the average number of online connections.

Data from iWiW

The iWiW (International Who Is Who) was launched on 14 April, 2002. It quickly became the best known SNS in Hungary and even the most visited national website in 2006. The number of users was limited in the first years but started to grow exponentially due to new functions introduced in 2005 (e.g., personal advertisements, picture uploads, public lists of friends, town classification, e-mail address). The system had 640,000 members with 35 million connections in April 2006, when Origo Ltd. (member of the Hungarian Telecom group) became the owner of the site. The number of registered users continued to rise afterwards; it had 1.5 million users in December 2006, more than 3.5 million users in October and more than 4 million users in December of 2008. Certainly, the competition among SNSs favoured Facebook in Hungary. Though the number of Hungarian Facebook users reached 3 million only in late 2011, Facebook outnumbered iWiW in terms of daily visitors in October 2010. Due to decreasing online traffic, the owners decided to close down iWiW servers, and the website stopped service by June 2014.

However, iWiW offers a unique approach to developing our argument for two reasons: First, it preceded Facebook in Hungary. Second, the geographical interpretation of diffusion is more straightforward because the original location can be identified easily in the case of iWiW, but Facebook might have spread to the country from multiple geographical locations.

A detailed spatial analysis on Hungary's information society claims that the distribution of iWiW users provides good description of internet diffusion in Hungary: The community of users grew faster in regional centres and larger settlements than in small towns (Tóth 2012). Furthermore, the rate of iWiW users among total local population correlates to a high degree with other spatial indicators of information society.

We collected data from the website in October 2008, when the number of users and the sum of connections were visible for every settlement[1]. The localisation of users based on profile information is considered to be problematic in papers focusing on OSN user and social media content localisation (Hecht *et al.* 2011). In iWiW, however, it was compulsory to choose a location from a scroll-down menu when registering as a user. Users' place of residence could easily have changed afterwards, and there certainly was no eligibility check. Thus, one might consider our profile-based location data to be a biased and occasionally updated census-type data.

Out of the total number of 3,135 Hungarian villages and cities, there was a minimum of 10 iWiW users in 2,426 settlements. The remaining 707 settlements did not have iWiW users in 2008; the majority of these latter locations were very small villages, but 128 of them had more than 500 and 23 had more than 1000 inhabitants. Altogether, 3,545,103 users established a total of 238,930,412 friendship ties.

Table 1 around here

[1] In 2008, each user could access the number of users in her/his settlement and also the aggregate number of connections of users in the settlement. Data were collected manually by Balázs Lengyel and Dorottya Vityi.

The two settlement-level variables we examine in detail are the rate of iWiW users among the total population (USERRATE) and the average number of iWiW friendship ties (AVERAGE NUMBER OF CONNECTIONS) with other users (within the same settlement or elsewhere).

USERRATE reports the extent to which the community has diffused to the settlement. The spatial distribution of this variable can be expected to depend on internet penetration and infrastructure. The AVERAGE NUMBER OF CONNECTIONS reveals how users in the settlement are involved in the online community. This variable takes a higher value if users have felt more enthusiasm in documenting previously established friendships on the online platform.[2]

We analyse how DISTANCE FROM THE CENTRE, measured by the Euclidean distance from Budapest, the capital of the country and origin of the OSN, affects these attributes. The model included additional location-dependent variables such as POPULATION, regional development measured by the rate of taxpaying citizens among the total population (TAXPAYERS), a composite telecommunication index (TELECOMMUNICATION), in which higher numbers indicate a better accessibility of telecommunication channels, and the share of registered library users among the population (LIBRARY), which refer to local cultural activities. Settlement-level dummies were also created, taking value of 1 if there is a university in the settlement (UNIVERSITY), if the settlement is a centre of a subregion (REGIONCENTRE), or if it is a city (CITY; in 2008, altogether 306 settlements were counted as cities). All these location-specific variables are expected to have a positive effect on the spatial levels of online social networking. The

[2] iWiW was a major innovation of its time in Hungary, and users typically spent a significant share of their online time finding current acquaintances and old friends who they had not seen in years.

location-specific variables were composed of the database of VÁTI (Hungarian Regional Development and Urbanism Ltd.). The definition of the variables and the descriptive statistics are summarised in Table 1, together with global autocorrelation indices.

Results

Two-way associations and spatial distribution – Plotting the two dependent variables (USERRATE and AVERAGE NUMBER OF CONNECTIONS) against major location-specific variables such as DISTANCE FROM THE CENTRE, POPULATION, and TELECOMMUNICATION unfolds the key point in our argument. Although the rate of users seems to depend positively or negatively on these offline factors, the average number of online friends seems to be constant or much less dependent on the offline environment (Figure 1).

Figure 1 around here

One can find a negative relationship between USERRATE and DISTANCE FROM THE CENTRE, in which the departure from the experienced maximum level is, in fact, growing in negative terms (Figure 1). As the distance increases, the probability of a lower USERRATE increases. The negative association between the distance from the centre and the spread of the online community is even more outstanding when one compares it with the positive relationship between USERRATE and other major offline variables, such as POPULATION or TELECOMMUNICATION.

However, such a strong relationship is not present in the association between the AVERAGE NUMBER OF CONNECTIONS and the DISTANCE FROM THE CENTRE; the latter variable seems to have only a slight positive effect on location-specific average involvement in the online community. The large majority of observations are not within the 95% confidence interval of the linear estimation, and the variation is higher in the right side of the distribution. In a similar vein, the AVERAGE NUMBER OF CONNECTIONS is independent of POPULATION and rises slightly along the TELECOMMUNICATION axis. We find that settlements do not differ significantly regarding the scale of users' connections.

The Pairwise Pearson correlation co-efficient between the DISTANCE FROM THE CENTRE and the AVERAGE NUMBER OF CONNECTIONS is positive and significant. The AVERAGE NUMBER OF CONNECTIONS takes higher values in more distant settlements. The correlation does not exceed the limit of 0.7 in any of the variable pairs; thus, the regression models that we introduce later are expected to be unbiased by multicollinearity (Table 2).

Table 2 around here

These findings suggest that OSN diffusion and the location-specific average number of online friends have different spatial characteristics. Enrolment in online social networks largely depends on the distance from the centre; more distant cities have relatively lower rates of users than larger ones. Meanwhile, once OSN reaches even a tiny place far from the centre, users will likely act and build networks similarly to citizens in urban areas; average users have almost the same number of connections in both central and peripheral locations.

However, when examining the spatial structure of the USERRATE and AVERAGE NUMBER OF CONNECTIONS variables, an interesting phenomenon unfolds: The landscapes drawn from the two variables are very different. It is evident from the maps that USERRATE and the AVERAGE NUMBER OF CONNECTIONS have adverse spatial structures concerning geographical distance from the centre (Figure 2).

Figure 2 around here

USERRATE is higher in settlements that are close to the capital, a finding that is consistent with the idea we got from the two-way association in Figure 1. The agglomeration of Budapest stands out from the country (Figure 2a); the same concerns the settlements along the Wien-Budapest highway and the area of Győr. Other locations in Trans-Danubia where user rate stands out are the surroundings of Lake Balaton and Pécs (the cultural capital of Europe in 2010). Regional and education centres (Szeged, Debrecen, Nyíregyháza, Miskolc) also surpass smaller towns in the Eastern part of the country.

On the contrary, despite the growing dispersal of the AVERAGE NUMBER OF CONNECTIONS in peripheral locations, the variable is visibly higher in settlements far from Budapest. Put differently, Budapest's agglomeration and the regional centres in the East do not stand out (Figure 2b). The two locations that have both an outstanding USERRATE and an AVERAGE NUMBER OF CONNECTIONS are the surroundings of Győr (Northwest) and Pécs (Southwest).

These results imply that the spatial characteristics of OSN diffusion and the average number of online friends do not coincide necessarily. One might perceive the dual-faced phenomenon of OSN geographies. First, the diffusion of the online community depends on the location, particularly the proximity to the centre. Second, the average number of online friends seems to be independent of offline factors; however, users can be even more active in building connections in some peripheral locations than in the centre.

Spatial autocorrelation analysis – A special supplementary attribute of the previously mentioned distance-dependence is that the adjacent spatial objects of the analysis could also be similar to one another in social and economic terms (Tobler 1970). Accordingly, we assume that neighbouring geographical objects typically have a somewhat similar USERRATE and AVERAGE NUMBER OF CONNECTIONS values by virtue of their relative geographical position. This phenomenon may show that virtual space is not independent of real geographical relationships. We measure spatial statistical similarity:

whether high values are typically located in neighbouring regions or are geographically dispersed and randomly located. (The question is naturally the same for low values.)

To explore neighbourhood effects, we examined first the global autocorrelation indices of USERRATE and the AVERAGE NUMBER OF CONNECTIONS. The indices of global Moran's I were calculated with one spatial weight matrix built up from 20 km threshold distance weights[3].

The Moran's I value of USERRATE was 0.28; a somewhat smaller but nonetheless significant positive spatial autocorrelation was measured for the AVERAGE NUMBER OF CONNECTIONS (see Table 1). Although the outcomes of the calculations are far from strong and the high absolute values of the results are still decisive; there are measurable neighbourhood effects in the dataset. These neighbourhood effects are locally rather variant; however, certain parts of the country are stably clustered (Figure 3).

Figure 3 around here

The local autocorrelation pattern of USERRATE reflect strong clusters in the agglomeration zone of Budapest and some smaller, but definitely still observable, clusters of high values around certain regional centres (Figure 3a). The low value clusters are typically observable in the Southwest and Northeast parts of the country. The map of the local autocorrelation pattern of the AVERAGE NUMBER OF CONNECTIONS also reflects spatial clustering processes; however, there are insignificant results for the centre parts of the country (Figure 3b). A very stable high value cluster is observable in the Northwest, whereas low value clusters are again typically located in peripheral areas.

[3] Settlements without iWiW users were omitted; therefore, we could not use rook or queen contiguity for spatial weight matrices.

Regression and spatial regression models – Two sets of models were built to test the effect of the DISTANCE FROM THE CENTRE on USERRATE (Table 3) and the AVERAGE NUMBER OF CONNECTIONS (Table 4) across 2,426 Hungarian settlements.

The estimation strategy was identical regarding both dependent variables. First, linear models were tested using OLS regressions that included DISTANCE FROM THE CENTRE as the explanatory variable and POPULATION, TAXPAYERS, TELECOMMUNICATION and LIBRARY as the control variables (Model 1). Then, the UNIVERSITY, REGIONCENTRE, and CITY dummy variables were introduced into the models separately (Models 2-3-4). Lagrange Multiplier tests were conducted in Models 1-2-3-4 to provide diagnostics for spatial autocorrelation in the OLS regression. Finally, spatial regression models were developed using maximum likelihood estimation, where the spatial weight matrix controlled for neighbourhood effects (Model 5). For this last model, we chose the one from previous OLS regressions with the highest R-square value. Because Robust LM-lag statistics were not significant in the OLS estimations, spatial error ML regressions were run. Lambda denotes the coefficient of the spatially correlated errors.

Spatial error models were developed to demonstrate that the effect of location-specific control variables remained significantly positive even after controlling for neighbourhood effects. Evidently, one cannot expect a significant effect of distance in the ML regression models because the level of DISTANCE FROM THE CENTRE is correlated very strongly across neighbouring regions.

Table 3 around here

DISTANCE FROM THE CENTRE has a negative and significant coefficient in the USERRATE models that remains stable even after inserting the various control variables

(Table 3)[4]. This finding indicates as the settlement distance to Budapest decreases, the share of iWiW users among the total population increases. The result suggests that the diffusion of the online social network is not independent of physical space, but distance from the central location has a deterring role in it. Furthermore, the finding strengthens the underlying conjecture that offline channels have a very important role in the spreading of online communities. The economic significance of the effect might stem from distance-related costs that have been previously associated with communication (Liben-Nowell *et al.* 2005, Storper and Venables 2004, Takhteyev *et al.* 2012, Tranos and Nijkamp 2012).

Table 4 around here

The effect of the DISTANCE FROM THE CENTRE on the AVERAGE NUMBER OF CONNECTIONS is significantly positive, and the effect is very stable through all the regression models (Table 4)[5]. Notably, this finding is not even disturbed by the ML spatial error model (Model 5 in Table 4)[6]. This finding suggests that as the distance from the capital increases, so does the average of number of friends.

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[4] The coefficient of POPULATION and TAXPAYERS become higher when settlements without any iWiW users are included in the regression because these new observations are very small and underdeveloped villages. The coefficient of DISTANCE FROM THE CENTRE remains negative but becomes insignificant when all settlements are included. We do not report these results in the tables.

[5] The coefficient of POPULATION and TAXPAYERS becomes higher when settlements without any iWiW users are included in the regression because these new observations are very small and underdeveloped villages. The coefficient of DISTANCE FROM THE CENTRE does not change substantially when all settlements are included. We do not report these results in the tables.

[6] The specification of the spatial error model is not without problems; the likelihood ratio tests remained highly significant. However, we do not aim to perfect the spatial model in this paper; we only intend to show that the effects of the control variables are stable.

The same set of control variables was used in both types of regression models. The POPULATION, TAXPAYERS, TELECOMMUNICATION, and LIBRARY variables have a positive effect in the USERRATE regressions, and all the coefficients are stable (Table 3). These results accord with the expectation that OSNs are more widely and actively used in settlements that are larger, have better economic conditions, have a telecommunications infrastructure that is more developed and have a cultural life that is stronger than average. We also find that a relatively higher share of citizens registered on the OSN is university towns, region centres, and cities, which suggests that settlement structure plays an important role in OSN diffusion.

The majority of the control variables have a positive, significant and stable effect in models focusing on the AVERAGE NUMBER OF CONNECTIONS (Table 4). However, the LIBRARY variable loses significance, and neither REGIONCENTRE nor CITY affects the location-specific average of online friendship (Models 3 and 4 in Table 4). Notably, the UNIVERSITY variable even has a negative and significant co-efficient that remains significant in the spatial error regression (Models 2 and 5 in Table 4). These results confirm that users had fewer online friends on average in university towns, but more online friendships were established in larger, more developed settlements with better internet access.

To sum up, we found that offline factors that specify geographical locations play a significant role in shaping the diffusion of OSNs and the average number OSN friends. The role of geographical locations in community diffusion might be interpreted by explaining the diffusion of online innovations with offline channels and networks. For example, a new OSN user might hear about the service from their 'real life' friends. However, the interconnectedness between the average number of connections and offline geography is surprising because the former seemed to be independent from the latter in our initial visualisations (see Figure 1). The coefficients of offline geography variables are significant when controlling for several of them simultaneously. Consequently, the number of network ties in OSNs might depend on the economic and social characteristics of spatial environments.

Furthermore, we also found an adverse effect of the distance from the centre of the country on community diffusion and average degree. The closer the settlement is to Budapest, the higher the rate of iWiW users is. This finding suggests that distance has a decaying effect on the diffusion of online communities because it might be more time consuming for the OSN to spread through offline channels and networks to distant places. However, iWiW users in peripheral locations of the country are more involved in documenting friendships online than users in geographical proximity to the capital. This latest finding is interesting because it might indicate that distant users took advantage of the online communication platform more than users close to the centre in the phase of the iWiW lifecycle when the data were collected.

Discussion

Online social networks have opened new opportunities for empirical research and will likely account for a growing share of scientific interest that aims for a closer understanding of online communication and human development. In this paper, we presented an initial attempt to establish a geography-related research line in this promising field of interdisciplinary focus.

We demonstrated here that OSNs are place dependent because offline economic, social, cultural, and settlement-structure functions can significantly explain the location-specific rate of users among the total population. However, as soon as individuals have a profile in the OSN, their online activity might be very similar, regardless of their settlement size or internet access. These are the paper’s main findings, which are novel contributions to the literature. In a nutshell, geographical location and cyberspace attributes are simultaneously present in OSN geographies. This finding may be interpreted as a promise that OSNs will provide us with new insights into online activities and may allow us to go further in the current “death of distance” debate.

Notably, we also found a controversial effect of the distance from the centre on the rate of users and the average number of connections. As the distance from the centre decreases, the rate of users among the total population increases. This finding indicates that distance might play a crucial role in the spread of online communities. On the contrary, the average number of documented online friendships is higher in settlements further away from the capital. This finding will be the basis of our future research in which the iWiW lifecycle will be traced on an individual level. A possible hypothesis to be tested in a subsequent paper is that users in the centre were more active in documenting their online friendship in the early phases of iWiW but became less active as the service went out of fashion, whereas users in peripheral areas became relatively more active in later phases. This future line of research will shed light on the role of user-level similarities in OSN diffusion because one can expect that different dimensions of proximities also affect the spatial diffusion of innovation (Boschma, 2005). Extra attention will be given to individual-level strategies in networking and the local cultures of OSN usage as possible threats for data distortion and geographical implementation (Graham 2010, Grabher and König 2012).

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Reference list

ACQUISTI, A. & GROSS R. (2009), Predicting Social Security numbers from public data. *Proceedings of the National Academy of Sciences* 106. pp. 10975-10980.

AHN, Y-Y, HAN, S., KWAK, H., EOM, Y-H., MOON, S. & JEONG H. (2007), Analysis of Topological Characteristics of Huge Online Social Networking Services. Proceedings of the 16th international conference on World Wide Web. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.87.2864&rep=rep1&type=pdf

ATKINSON, R. (1998), Technological change and cities. *Cityscape: A Journal of Policy Development and Research* 3, pp. 129-171.

BACKSTROM, L., BOLDI, P., ROSA, M., UGANDER, J. & VIGNA, S. (2011), Four degrees of separation. DOI: arXiv1111.4570v1. http://people.cam.cornell.edu/~jugander/papers/websci12-fourdegrees.pdf

BARABÁSI, A. L. & ALBERT, R. (1999), Emergence of scaling in random networks. *Science* 286, pp. 509-512.

BATTY, M. (1993), The geography of cyberspace. *Environment and Planning B: Planning and Design* 20, pp. 615–616.

BENEDIKT, M. (1991), Cyberspace: some proposals. *In*: M. BENEDIKT, ed., *Cyberspace: first steps,* pp. 119-224. Cambridge: MIT Press.

BERG, M. (2011), Checking in at the urban playground: digital geographies and electronic flâneurs. *In*: F. Comunello, ed., *Networked Sociability and Individualism: Technology for Personal and Professional Relationships,* pp. 169-194, Hershey, PA: IGI Global.

BORGATTI, S.P., MEHRA, A., BRASS, D.J. & LABIANCA, G. (2009) Network analysis in the social sciences. *Science* 323, pp. 892-895.

BOSCHMA, R. A. (2005) Proximity and innovation. A critical assessment. *Regional Studies* 39, pp. 61-74.

boyd, d. (2008), Why Youth ♥ Social Network Sites: The Role of Networked Publics in Teenage Social Life. *In*: D. Buckingham, ed., *Youth, Identity, and Digital Media,* pp. 119–142, Cambridge, MA: MIT Press.

boyd, d. & ELLISON, N. B. (2007), Social Network Sites: definition, history, and scholarship. *Journal of Computer Mediated Communication* 13, pp. 210-230.

BRUNN, S. D. & LEINBACH, T. R. (1991), *Collapsing space and time: Geographic Aspects of Communication and Information.* New York: Harper Collins Academic.

CAIRNCROSS, F. (1997) *The death of distance. How the communication revolution will change our lives.* Boston? Harvard Business School Press.

CASTELLS, M. (1996), *The Rise of the Network Society. The Information Age: economy, society and culture*. Oxford: Blackwell Publishers.

CRAMPTON, J. W., GRAHAM, M., POORTHUIS, A., SHELTON, T., STEPHENS, M., WILSON, M.W. & ZOOK, M. (2013) Beyond the geotag: situation ‘big data’ and leveraging the potential of the geoweb. *Cartography and Geographic Information Science* 40, pp130-139.

DARAGANOVA, G., PATTISON, P., KOSKINEN, J., MITCHELL, B., BILL, A., WATTS, M. & BAUM, S. (2012) Networks and geography: modelling community network structures as the outcome of both spatial and network processes. *Social Networks* 34, pp. 6-17.

DEVRIENDT, I., DERUDDER, B. & WITLOX, F. (2008), Cyberplace and cyberspace: two approaches to analyzing digital intercity linkages. *Journal of Urban Technology* 15, pp. 5-32

D'IGNAZIO, A. & GIOVANNETTI, E. (2007), Spatial Dispersion of Interconnection Clusters in the European Internet. *Spatial Economic Analysis* 2, pp. 219-36.

DODGE, M. (2001), Cybergeography. *Environment and Planning B: Planning and Design* 28, pp. 1-2

ELLISON, N., STEINFIELD, C. & LAMPE, C. (2006), Spatially Bounded Online Social Networks and Social Capital: The Role of Facebook. Paper presented at the Annual Conference of the International Communication Association, 19-23 June http://www.icahdq.org/conf/2006confprogram.asp

ELLISON, N. B., STEINFIELD, C. & LAMPE, C. (2007), The Benefits of Facebook Friends: Social Capital and College Students' Use of Online Social Network Sites. *Journal of Computer-Mediated Communication* 12, pp. 1143-1168

ELWOOD, S., GOODCHILD, M.F.& SUI, D.Z. (2012) Researching Volunteered Geographic Information: spatial data, geographic research, and new social practice. *Annals of the Association of American Geographers* 102, pp. 571-590.

ESCHER, T. (2007), The Geography of Online Social Networks. Presentation at Oxford Internet Institute September 5 http://people.oii.ox.ac.uk/escher/wp-content/uploads/2007/09/Escher_York_presentation.pdf

EXPERT, P., EVANS, T.S., BLONDEL, V.D. & LAMBIOTTE, R., (2011) Uncovering space-independent communities in spatial networks. *PNAS* 108, pp. 7663-7668.

FABRIKANT, S.I. (2000), The Geography of Semantic Information Spaces. Paper presented at GIScience 2000 – First International Conference on Geographic Information Science http://www.giscience.org/GIScience2000/papers/016-Fabrikant.pdf

FELDMAN, M. P. (2002), The internet revolution and the geography of innovation. *International Social Science Journal* 54**,** pp. 47-56.

FERNBACK, J. (2007), Beyond the diluted community concept: a symbolic interactionist perspective on online social relations. *New Media Society* 9, pp. 49-69.

GORMAN, S. P. (2002), Where are the web factories: The urban bias of e-business location” *Tijdschrifts voor Economische en Sociale Geografie* 93, pp. 522-536.

GRABHER, G. & KÖNIG, J. (2012), Performing network theory? Reflexive relationship management on social network sites. Paper presented at the Embeddedness and Beyond: Do Sociological Theories meet Economic Realities? Conference October 25-28 http://esconf2012.hse.ru/

GRAHAM, M. (2010), Neogeography and the palimpsest of place: web 2.0 and the construction of a virtual earth. *Tijdschrift voor Economische and Sociale Geografie* 101, pp. 422-436.

GREENHOW, C. (2011), Learning and social media: What are the interesting questions for research? *International Journal of Cyber Behavior, Psychology and Learning* 1, pp. 36-50.

GRILICHES, Z. (1957), Hybrid Corn: an exploration in the economics of technological change. *Econometrica*, 25, 4, pp. 501-522.

HÄGERSTAND, T. (1967), *Innovation diffusion as a spatial process*. Chicago: University of Chicago Press.

HAKLAY, M., SINGLETON, A. & PARKER, C. (2008), Web Mapping 2.0: the Neogeography of the GeoWeb. *Geography Compress* 6, pp. 2011-2039.

HAYES, B. (1997), The Infrastructure of the Information Infrastructure. *American Scientist* 85, pp. 214-218.

HECHT, B., HONG, L., SUH, B. & CHI, E. H. (2011), Tweets from Justin Bieber’s heart: the dynamics of the “location” field in user profiles. *Proceedings of the ACM Conference on Human Factors in Computing Systems*, pp. 237-246, New York: ACM Press.

HOGAN, B. (2009), A comparison of on and offline networks through the Facebook API. http://papers.ssrn.com/sol3/papers.cfm?abstract id=1331029

JONES, S. G. (1995), Understanding community in the information age. *In*: S. G. JONES, ed., *Cybersociety: computer-mediated communication and community*, pp. 10-35, London: Sage.

KITCHIN, R. M. (1998), Towards geographies of cyberspace. *Progress in Human Geography* 22, pp. 385-406.

KUMAR, R., NOVAK, J. & TOMKINS, A. (2006), Structure and evolution of online social networks. *In: Proceedings of 12th International Conference on Knowledge Discovery in Data Mining*, pp. 611-617, New York: ACM Press.

LIBEN-NOWELL, D., NOVAK, J., KUMAR, R., RAGHAVAN, P. & TOMKINS, A. (2005), Geographic routing in social networks. *Proceedings of the National Academy of Sciences of USA* 102, pp. 11623-11628.

LOBBURI, P. (2012) Maintaining long-distance friendships: communication practices for seeking and providing social support across geographic divides. *Journal of International Education Research*, 8, pp. 125-133.

MORGAN, K. (2001), The exaggerated death of geography: localised learning, innovation and uneven development. http://www.utoronto.ca/onris/research_review/WorkingPapers/WorkingDOCS/Working01/Morgan01_Death.pdf

NEGROPONTE, N. (1995), *Being digital.* London: Coronet.

ONNELA, J-P., ARBERSMAN, S., GONZALEZ, M.C., BARABÁSI, A-L. & CHRISTAKIS, N.A. (2011) Geographic constraints of social network grious. *PLoS ONE*, 6, 4, e16939

SCELLATO, S., MASCOLO, C., BARTHELEMY, M. & VESPIGNANI, A. (2010) Distance matters: geo-social metrics for online social networks. *Proceedings of the Third Conference on Online Social Networks*, USENIX Association, Berkley, California.

STORPER, M. & VENABLES, A. (2004), Buzz: face-to-face contact and the urban economy. *Journal of Economic Geography* 4, pp. 351-370.

SUCHÁČEK, J. (2004), The Emergence of the Geography of Networks. http://www.kakanien.ac.at/beitr/ncs/JSuchacek1.pdf

TAKHTEYEV, Y., GRUZD, A. & WELLMAN, B. (2012), Geography of Twitter networks. *Social Networks* 34, pp. 73-81.

TOBLER, W. A. (1970), Computer Model Simulating Urban Growth in the Detroit Region. *Economic Geography* 47, pp. 234-240.

TÓTH, P. (2012), *Magyar települések az információs társadalomban* (PhD Thesis, Széchenу István University, Győr).

TRANOS, E. (2011), The topology and the emerging urban geographies of the Internet backbone and aviation networks in Europe: a comparative study. *Environment and Planning A* 43, pp. 378 – 392.

TRANOS, E. & NIJKAMP, P. (2012), The death of distance revisited: cyberplace, physical and relational proximities. Working Paper Tinbergen Institute TI 2012-066/3 http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2103024

TRAUD, A., KELSIC, E., MUCHA, P. & PORTER, M. (2008), Community structure in online collegiate social networks. http://cds.cern.ch/record/1124061

UGANDER, J., KARRER, B., BACKSTROM, L. & MARLOW, C. (2011), The anatomy of the facebook social graph. http://arxiv.org/abs/1111.4503

WELLMAN, B. (2001), Phisical place and cyberplace: the rise of personalized networking. *International Journal of Urban and Regional Research* 25, pp. 227-252.

WELLMAN, B. (2002), Little boxes, glocalization, and networked individualism. Centre for Urban and Community Studies, University of Toronto. http://homes.chass.utoronto.ca/~wellman/publications/littleboxes/littlebox.PDF

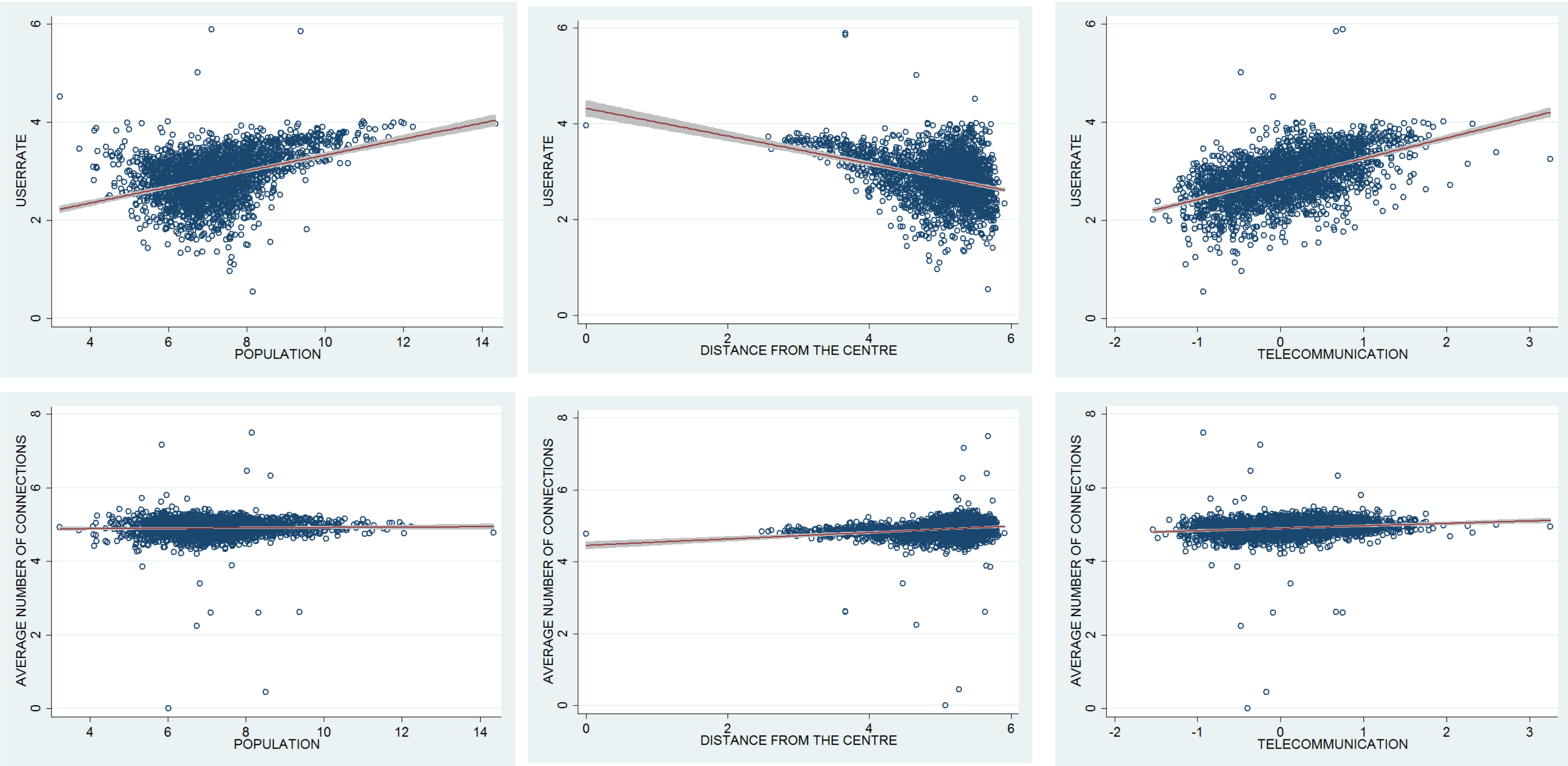
YARDI, S. & boyd, d. (2010), Tweeting from the town square: measuring geographic local networks. Paper presented at AAAI of the International Conference on Weblogs and Social Media May 23-26 http://yardi.people.si.umich.edu/pubs/Yardi_TownSquare10.pdf

ZHAO, S., GRASMUCK, S. & MARTIN, J. (2008), Identity Construction on Facebook: Digital Empowerment in Anchored Relationships. *Computers in Human Behavior* 24, pp. 1816-1836.

ZOOK, M.A. (2002), Grounded capital: venture financing and the geography of internet industry, 1994-2000. *Journal of Economic Geography* 2, pp. 151-177.

ZOOK, M.A. (2003), Underground globalization: mapping the space of flows of the Internet adult industry. *Environment and Planning A* 35, pp. 1261-1286.

Figure 1: Settlement level association between user rate and the average number of connections with population size, distance from the centre and the complex telecommunication index, 2008



Note: 2,426 settlements are plotted against the linear-regression fitted values and 95% confidence interval. All variables are transformed to natural logarithm values except TELECOMMUNICATION, where standardised values are presented.

Figure 2a: User rate values, 2008

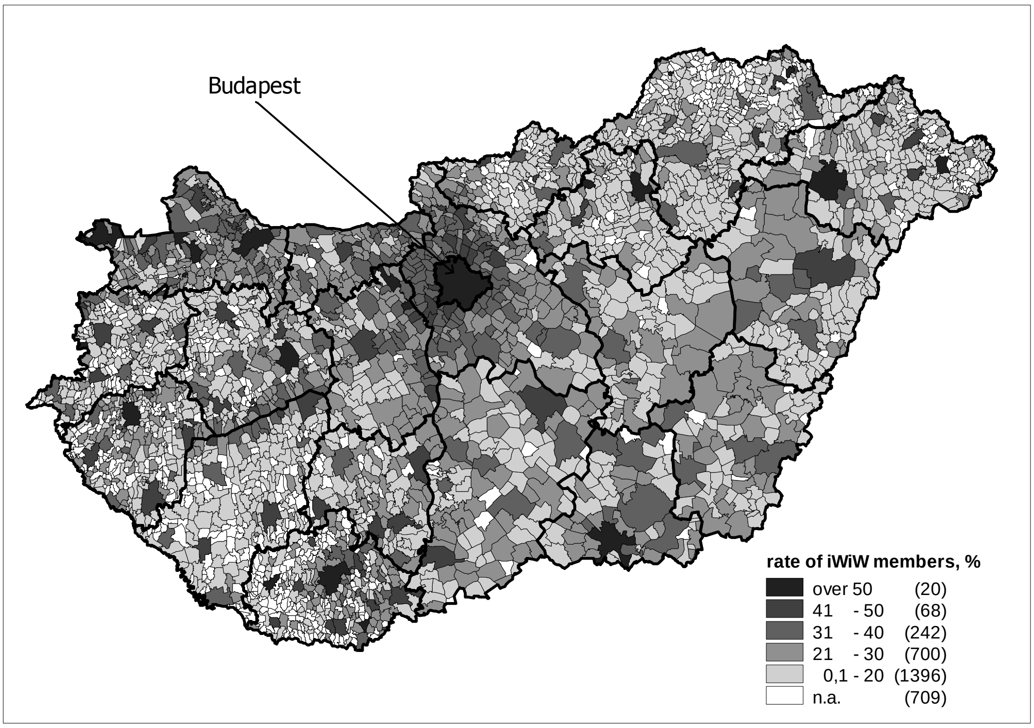


Figure 2b: Average number of connections, 2008

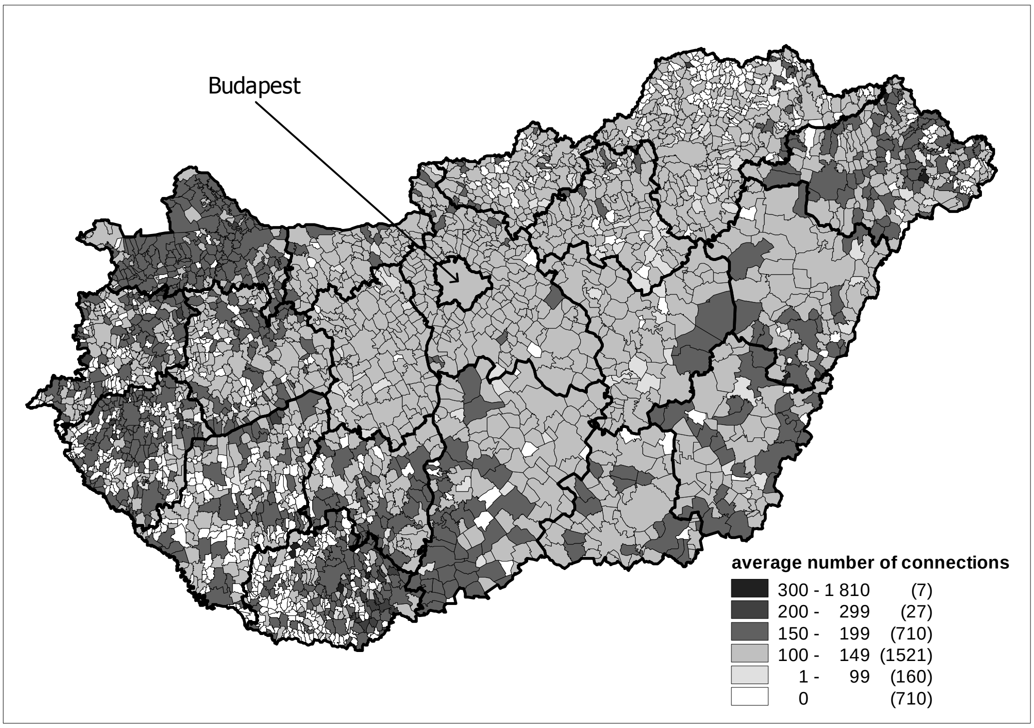
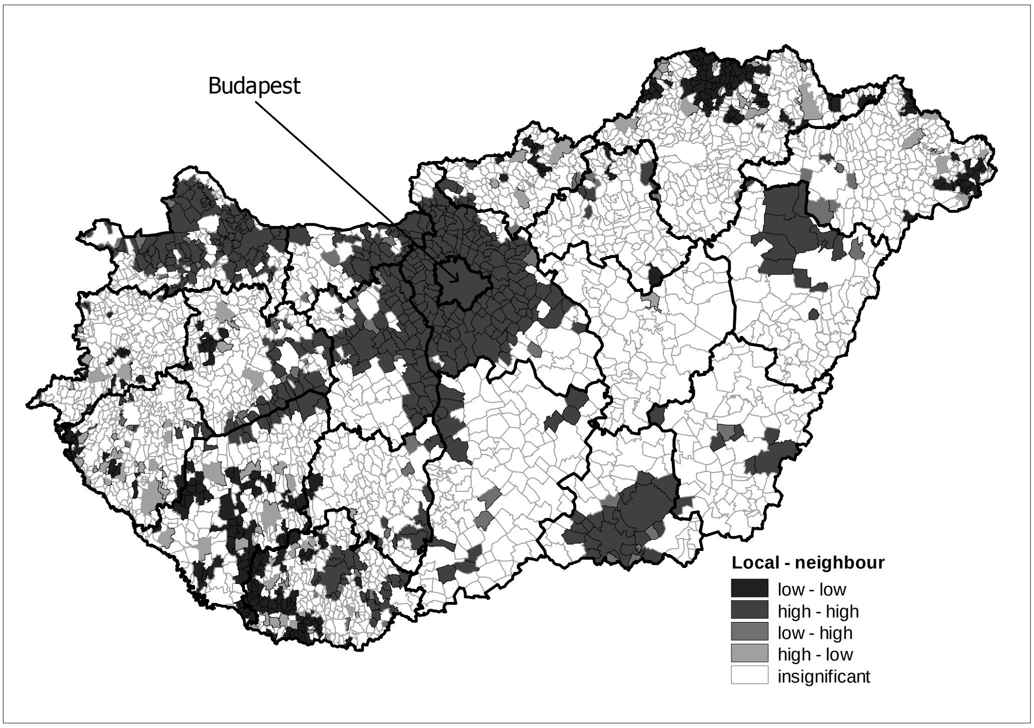
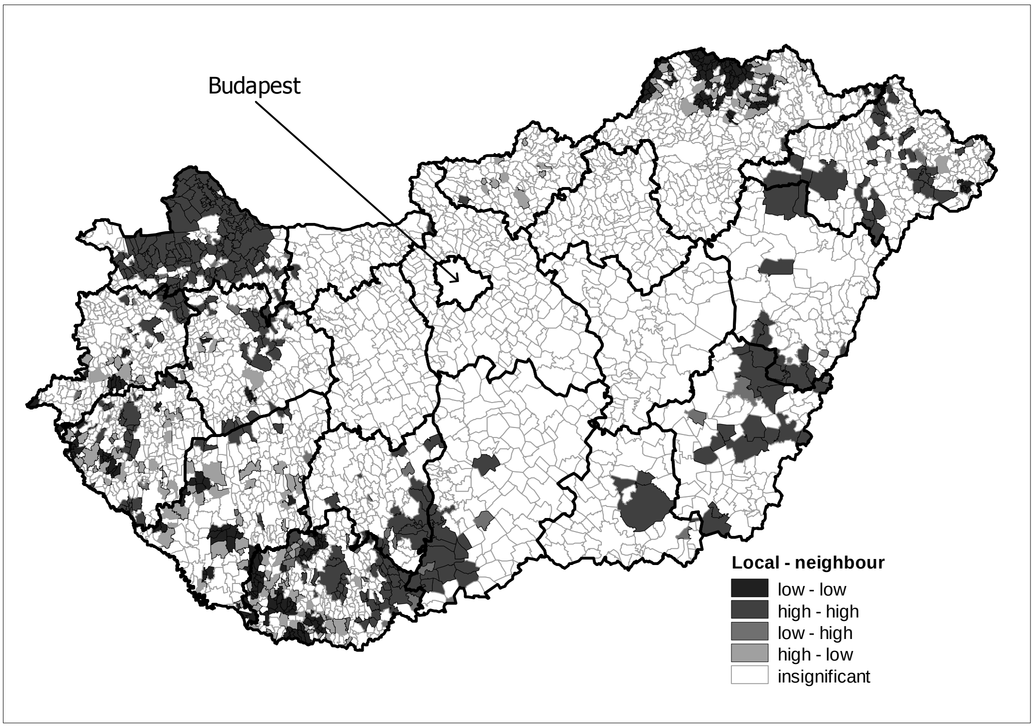


Figure 3a: Local autocorrelation pattern of user rate values



Notes: The map represents results under 0.05 significance with randomness set to 999 permutations.

Figure 3b: Local autocorrelation pattern of average number of connections



Notes: The map represents results under 0.05 significance with randomness set to 999 permutations

Table 1: Variable description

	Variable	Description	N	Min	Max	Mean	St.dev.	Moran
1	USERRATE	Natural logarithm of rate of iWiW users among the population	2,426	0.548	5.896	2.882	0.486	0.280
2	AVERAGE NUMBER OF CONNECTIONS	Natural logarithm of the total number of iWiW connections over total number of iWiW users	2,426	0	7.498	4.903	0.271	0.187
3	POPULATION	Natural logarithm of the total population	2,426	3.219	14.342	7.215	1.171	0.282
4	DISTANCE FROM THE CENTRE	Natural logarithm of distance measured by km on the road from Budapest	2,426	0	5.913	5.005	0.578	0.950
5	TAXPAYERS	Rate of taxpaying citizens among the total population	2,426	10.097	61.070	40.096	7.251	0.449
6	TELECOMMUNICATION	Standardised average of internet, cable television, telephone main lines (ISDN included), and cell phone subscriptions	2,426	-1.534	3.247	0.081	0.615	0.529
7	LIBRARY	Rate of library users among the total population	2,426	0	71.748	8.366	9.728	0.128
8	UNIVERSITY	Dummy variable taking a value of 1 if the settlement accounts for a university department	2,426	0	1	0.018	0.136	-0.001
9	REGIONCENTRE	Dummy variable taking a value of 1 if the settlement is the centre of its subregion.	2,426	0	1	0.072	0.258	-0.019
10	CITY	Dummy variable taking a value of 1 if the settlement is administratively a city	2,426	0	1	0.125	0.331	0.042

Notes: Global Moran Indices were calculated by the application of 20 km threshold distance weights.

Table 2: Pairwise Pearson correlation values of variables

		1	2	3	4	5	6	7	8	9
USERRATE	1									
AVERAGE NUMBER OF CONNECTIONS	2	0.182*								
POPULATION	3	0.393*	0.022							
DISTANCE FROM THE CENTRE	4	-0.344*	0.191*	-0.319*						
TAXPAYERS	5	0.569*	0.214*	0.131*	-0.272*					
TELECOMMUNICATION	6	0.528*	0.150*	0.149*	-0.406*	0.677*				
LIBRARY	7	0.172*	0.011	0.321*	-0.047	-0.003	-0.021			
UNIVERSITY	8	0.238*	0.034	0.415*	-0.066*	0.121*	0.209*	0.128*		
REGIONCENTRE	9	0.384*	0.083*	0.564*	-0.048	0.167*	0.186*	0.232*	0.464*	
CITY	10	0.381*	0.077*	0.582*	-0.101*	0.124*	0.108*	0.250*	0.149*	0.618*

Note: * denotes statistical significance at the 1% level

Table 3: Regression models for USERRATE

	OLS [1]	OLS [2]	OLS [3]	OLS [4]	ML Spatial Error [5]
DISTANCE FROM THE CENTRE	-0.057 ***	-0.061 ***	-0.090 ***	-0.078 ***	-0.050
	(-4.04)	(-4.27)	(-6.23)	(-5.55)	(-1.54)
POPULATION	0.108 ***	0.103 ***	0.065 ***	0.059 ***	0.060 ***
	(15.70)	(13.60)	(8.07)	(7.40)	(7.28)
TAXPAYERS	0.024 ***	0.025 ***	0.024 ***	0.024 ***	0.026 ***
	(18.35)	(18.42)	(18.32)	(18.34)	(19.17)
TELECOMMUNICATION	0.169 ***	0.160 ***	0.146 ***	0.161 ***	0.146 ***
	(10.07)	(9.54)	(8.81)	(9.83)	(8.23)
LIBRARY	0.004 ***	0.004 ***	0.004 ***	0.004 ***	0.004 ***
	(5.70)	(5.70)	(5.12)	(4.92)	(5.78)
UNIVERSITY		0.107 *			
		(1.79)			
REGIONCENTRE			0.331 ***		
			(9.57)		
CITY				0.297 ***	0.273 ***
				(11.18)	(11.10)
LAMBDA					0.720 ***
					(20.31)
CONS	1.344 ***	1.396 ***	1.815 ***	1.788 ***	1.578 ***
	(12.27)	(12.32)	(15.23)	(15.63)	(-7.88)
N	2,426	2,426	2,426	2,426	2,426
R^2	0.47	0.47	0.48	0.49	0.57
F test	419.35 ***	351.92 ***	377.98 ***	388.57 ***	
VIF	1.51	1.53	1.64	1.62	
Robust LM-Error	674.12 ***	677.38 ***	688.24 ***	627.93 ***	
Robust LM-Lag	2.06	1.98	0.12	1.02e-5	
LR-Error					341.64 ***

Notes: OLS regression models use the Huber-White estimation method, whereas the spatial error model is estimated using a maximum likelihood estimator. t-statistics are reported in parentheses beneath the coefficients in OLS models (Models 1-4), whereas the z-values are reported for spatial error models (Model 5). ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. F tests assess the null hypothesis that all coefficients are zero. The spatial weight matrix is based on 20 km threshold distance weights. Because LM-Lag and LM-Error statistics are both highly significant, we report only Robust LM-Lag and Robust LM-Error statistics.

Table 4: Regression models for AVERAGE NUMBER OF CONNECTIONS

	OLS [1]		OLS [2]		OLS [3]		OLS [4]		ML Spatial Error [5]	
DISTANCE FROM THE CENTRE	0.152	***	0.155	***	0.153	***	0.150	***	0.145	***
	(14.99)		(15.10)		(14.65)		(14.67)		(6.58)	
POPULATION	0.018	***	0.022	***	0.019	***	0.013	**	0.037	***
	(3.68)		(4.10)		(3.24)		(2.22)		(6.54)	
TAXPAYERS	0.007	***	0.007	***	0.007	***	0.007	***	0.006	***
	(7.74)		(7.64)		(7.74)		(7.65)		(6.16)	
TELECOMMUNICATION	0.060	*	0.064	***	0.060	***	0.059	***	0.054	**
	(5.03)		(5.29)		(5.03)		(4.99)		(4.11)	
LIBRARY	1.129e-4		1.138e-4		1.246e-4		4.125e-5		4.343e-5	
	(0.20)		(0.20)		(0.22)		(0.07)		(0.07)	
UNIVERSITY			-0.077	*					-0.098	**
			(-1.81)						(-2.47)	
REGIONCENTRE					-0.007					
					(-0.30)					
CITY							0.030			
							(1.57)			
LAMBDA									0.523	***
									(10.54)	
CONS	3.706	***	3.668	***	3.690	***	3.753	***	3.648	***
	(47.61)		(45.53)		(43.16)		(45.07)		(28.19)	
N	2,426		2,426		2,426		2,426		2,426	
R^2	0.13		0.13		0.13		0.13		0.22	
F test	70.36	***	59.23	***	58.63	***	59.08			
VIF	1.51		1.53		1.64		1.62			
Robust LM-Error	101.05	***	106.17	***	102.17	***	97.62	***		
Robust LM-Lag	2.24		1.86		2.07		2.66			
LR-Error									225.50	***

Notes: OLS regression models use Huber-White estimation method, while Spatial error model is estimated using Maximum-likelihood estimator. t-statistics are reported in parentheses beneath coefficients in OLS models (Model 1-4), whereas z-values are reported for spatial error models (Model 5). ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. F test assesses the null hypothesis that all coefficients are zero. The spatial weight matrix is based on 20 km threshold distance weights. Because LM-Lag and LM-Error statistics are both highly significant, we report only Robust LM-Lag and Robust LM-Error statistics.