# Estimating Diffusion Rates for Telecommunications: Evidence from European Union

Agiakloglou, Christos and Karkalakos, Sotiris

2006

# A SPATIAL AND ECONOMIC ANALYSIS FOR TELECOMMUNICATIONS: EVIDENCE FROM THE EUROPEAN UNION.

**Christos Agiakloglou**
*University of Piraeus*

**Sotiris Karkalakos***
*Keele University and University of Illinois at Urbana-Champaign*

Submitted: January 2007.

**Abstract**

This paper evaluates the role of a number of determinants of telecommunication services in European Union. We use a logistic model with spatial covariates to estimate the demand function for telecommunications in the Union. Our results show that different types of interconnections generate diverse estimates for country specific demand. The impact on telecommunications from countries with spatial, economic or social similarities differs based on those characteristics. Omitted variable bias from not modeling spatial interdependence is limited in models under spatial connectivity criteria. This satisfies the statistical inference drawn by previous empirical studies regarding determinants of telecommunications.

*JEL classification*: C21, C22, C23, L96

*Keywords*: decay effect, telephone traffic demand, spatial econometrics.

* Sotiris Karkalakos (corresponding author): Department of Economics, Keele University, Keele – Staffs, ST5 5BG, United Kingdom. *Email address:* s.karkalakos@econ.keele.ac.uk. Christos Agiakloglou, e*mail address:* agaklis@unipi.gr

## I. Introduction

Over the last few years, the telecommunications sector has received an increasingly attention in the economic literature and a large volume of theoretical and empirical work has been published in this area. The telecommunications market has changed to a more deregulated environment (Armstrong 1998) following the rules established by regulatory authorities and the demand for telecommunications services has increased tremendously as a result of the expansion of the economic activities of many multinational organizations. This paper focuses on explaining the demand for international telecommunications at a European country level.

There are a number of papers in the existing literature that are related to our work. Gatto et al. (1988) model residential demand by developing systems of five interdependent equations, corresponding to alternative ways of placing a call for each state. However, they do not apply a *spatial* econometric framework and thus their results may suffer significant bias. Interestingly, Christaller (1966) uses the number of telephone stations per person to develop a hierarchy of centers among Southern Germany's cities in 1963 and illustrate his central place theory (CPT). Green (1955) employs telephone call data to define the common boundary of the hinterlands of New York City and Boston. Various inter-city flows (e.g., migration, commuting, and tourism) have been used to analyze regional settlement structures, uncover central place hierarchies, delineate functional and nodal sub-regions, and identify regional disparities (e.g., core periphery). The latter regional structure motivates the *social* correlation of telecommunications. Finally, De Fontenay and Lee (1983) analyze residential calls between British Columbia and Alberta. They find that call duration has an inverse relationship with price (*economic* factors). All the above results justify the empirical formulation of our model. However, the contribution most closely related to ours is that of Gruber and Verboven (2001) who studied the technological determinants of mobile telecommunication services in the European Union and their analysis provided us with considerable insights of the workings of telecommunications market in Europe. In contrast to Gruber and Verboven (2001) and considering the results of the existing empirical literature[1], we analyze the determinants of demand for telecommunications and evaluate them using a multidimensional method (spatial econometrics). Thus, the contribution of the paper is three-fold: (i) decompose the impact of alternative factors that stimulate the demand for telecommunications, (ii) illustrate the effect of geographic proximity, trade and tourism flows to

[1] In this lieu, several empirical studies, such as Agiakloglou and Yiannelis (2005), Bewley and Fiebig (1988), Acton and Vogelsand (1992), Madden and Savage (2000), Sandbach (1996), Garin Munoz and Perez Amaral (1998), and Wright (1999) have tried to estimate price elasticities for international telecommunications demand for different countries based on time series data.

the demand for telecommunication services per country and, (iii) modify and extent the model of Gruber and Verboven (2001) to correct for multifactor bias of the estimates.

We take a more general look (Blonigen et al. 2006) at empirically modeling spatial interactions in demand for telecommunications and ask three fundamental questions not yet addressed by the previous literature[2]. The answers to those questions are the innovations of this paper. First, to what extent does omission of spatial interactions bias affects coefficients on the traditional regressor matrix in empirical telecommunications studies? Significant bias would call into question much of the existing empirical work and inference. Second, how are spatial relationships estimated using alternative specifications of *connectivity effects* (social and economic)? Given the existing literature, an obvious issue to examine is the differences across those criteria and whether their presence affects the results. Finally, we examine the evidence of country specific effects. The described approximation may be viewed as an alternative extension of the framework of technological determinants described in Gruber and Verboven (2001) for the telecommunications services.

The reminder of the paper proceeds as follows. Section II discusses the empirical strategy of estimation along with the data. Section III shows the empirical results and illustrates the country-specific effects, whereas section IV presents some concluding remarks.

## II. Empirical Strategy

Connectivity effects cannot be ignored from any analysis as long as the data supports such evidence (Zucker et al. 1998). Several factors, such as labor mobility, trade between regions, knowledge diffusion and more generally regional spillovers, may lead to various interconnections among European countries. Thus, the objective of this study is to determine demand elasticities for telecommunications taking into consideration various connectivity effects. Having identified the objective, we turn the discussion in choosing the proper model specification.

### A. Model Specification

The demand for international telecommunications of a country $i$ is defined as the amount of calling time used during some period of time, where the calling time is distributed over different distances. Let $m(d, g, t)$ denotes the calling time in distance zone $d$, with $g$ denoting the local economic characteristics, such as, for example, per

[2] The performance of the telecommunications market has been examined by several research papers, such as the one by Kiss and Lefebvre (1987) in which they applied a variety of telecommunications cost models to American firms or those by Laffont and Tirole (1993 and 2000) where they focused their research on regulatory framework models and on how to make regulation more efficient. In fact, they concluded that a good regulatory framework requires cost and demand information. Gasmi *et al.* (1999) indicate that despite efficiency gains from regulatory schemes, consumers might experience significant loses.

capital income and population density and $t$ is the time period. The demand for international telecommunications [$m(d, g, t)$] is a function of a vector $x$ of explanatory variables. Following Park *et al.* (1983) approach and assuming that the demand elasticity for calling time is proportional to price and that there are no cross price effects, we use the following relationship (*Specification 1)* for estimating demand equation[3]:

$$m_{i,t} = x_{i,t}\beta + k\sum_{\substack{j=1 \\ i\neq j}}^{n} w_{ij} m_{j,t} + \varepsilon_{i,t} \tag{1}$$

where $w_{ij}$ is the vector of the connectivity (spatial[4]) weights for $n$ countries (with $w_{ii} = 0$; Anselin 1988) and $k$ is the connectivity parameter also known as spatial autocorrelated parameter.[5] If $k$ is zero there will be no neighboring effect. Without the term $k\sum_{\substack{j=1 \\ i\neq j}}^{n} w_{ij} m_{j,t}$ equation (1) can be easily estimated provided that the error process shows no temporal correlations, so that the lagged $m$ is independent of the error process. Recent work on this model can be found in Kelejian and Prucha (2005).

In this model, the dependent variable is affected by the values of the dependent variable in nearby units, with "nearby" suitably defined. However, in many cases there may be several possible networks or forms of dependence that can be included in the model[6]. For example, it is possible to generalize the spatial autoregressive model (1) by using two distinct vectors $w_{ij1}$ and $w_{ij2}$ of spatial weights in which case the model becomes (*Specification 2)*:

$$m_{i,t} = x_{i,t}\beta + k_1\sum_{\substack{j=1 \\ i\neq j}}^{n} w_{ij1} m_{j,t} + k_2\sum_{\substack{j=1 \\ i\neq j}}^{n} w_{ij2} m_{j,t} + \varepsilon_{i,t} \tag{2}$$

where $k_1$ and $k_2$ are the relative connectivity parameters needed to be estimated. The expanded autoregressive model (2) is estimated as the standard spatial autoregressive model, provided that the two matrices are

[3] Under the condition that equation (1) converges to a balanced growth path in which the rate of telecommunications services is equal across European countries.

[4] In spatial econometrics the structure of dependence between observations is assumed to be known by the researcher and not to be estimated. Indeed, this structure is given by what is known as the "connectivity matrix", which specifies the degree of connectivity (weights) between any two observations. Let the connectivity matrix denoted by $W$, where a typical element $w_{ij}$ has a value greater than 0, if the observations $i$ and $j$ are connected.[4] By convention, units are not considered to be connected to themselves, so any diagonal entry $w_{ii} = 0$. The connectivity matrix is standardized so that each row vector $w_i$ sums to unity. As a consequence, it is not critical to worry about the units to measure connectivity, since $W$ is invariant to affined transformations.

[5] The term spatial autocorrelation refers to the coincidence of attribute similarity and locational similarity as discussed by Anselin (1988 and 2002).

[6] The model is analogous to the temporal autoregressive model that is used, to test, for example habit-persistence theory. Because the full vector of l.h.s variables also appears on the r.h.s, this model would be particularly similar to a hypothetical temporal autoregressive model, where the present is influenced by both the past and the future. In contrast to the time domain, spatial lag operators imply a shift over space, but are restricted by some complications that arise when one tries to make analogies between the time and space domains (Cressie 1993).

sufficiently different and that do not contain entirely overlapping information.[7] Lacombe (2004) uses a similar model to estimate parameters distinguishing within-state unit and between-state unit effects of welfare programs on female labor force participation.

Moreover, the equation (2) can be further expanded, as suggested by Zucker *et al.* (1998), by using the two distinct vectors of connectivity effects $w_{ij1}$ and $w_{ij2}$ with exogenous variables as follows (*Specification 3)*:

$$m_{i,t} = x_{i,t}\beta + k_1 \sum_{\substack{j=1 \\ i \neq j}}^{n} w_{ij1} m_{j,t} + k_2 \sum_{\substack{j=1 \\ i \neq j}}^{n} w_{i2} m_{j,t} + \rho_1 \sum_{\substack{j=1 \\ i \neq j}}^{n} w_{ij1} w_{ij2} x_{j,t}^{s} + \rho_2 \sum_{\substack{j=1 \\ i \neq j}}^{n} w_{ij1} w_{ij2} x_{j,t}^{v} + \varepsilon_{i,t} \tag{3}$$

where the full vector of exogenous variables is defined as $(x_i, x_j^s, x_j^v)$, meaning that in this case the explanatory variables are divided into three groups with $x_i$ denoting the exogenous variables of general interest (i.e., prices), $x_j^s$ the exogenous variables related to neighboring (j) infrastructure (i.e., number of lines per country) and $x_j^v$ the exogenous variables related to neighboring economic prosperity (i.e., GDP).

Consequently, we estimate all *specifications* by using Instrumental Variable (IV) method (Brueckner 2003) and employing three different distance weight matrices defined as: a) a binary distance measure of contiguity, b) an inverse distance measure of contiguity and c) a *k*-neighbors measure of contiguity for *k* = 6. Beside the distance matrix, we consider an economic weight matrix, using as index the volume of trade, and a social weight matrix, using as index the flow of tourist.

In a geographic context, the elements of the connectivity matrix are determined purely by physical distance.[8] However, in a non-geographic context, the notion of "distance" is determined by the trade volume and by the number of tourists. We consider as neighbors, countries with similar volume of trade flows. The trade connectivity matrix differs from the previous distance matrix in two notable ways. First, the trade matrix consists of weights where the importance of another state *j* to state *i* is given by the volume of the dyadic trade flow between *i* and *j* as a proportion of country's *i* total trade, whereas the distance matrix assigns equal weights to any geographical neighbor. Second, the trade connectivity matrix weights large trading partners much more heavily than smaller trading partners, whereas in the distance matrix, any neighbor of *i* must always have *j* as a non-trivial neighbor. Therefore, the elements of trade connectivity matrix are defined as:

$$S_{ji} = 1 - [\sum_{i} \sum_{j} \left| trade_j - trade_i \right| / K_{ji}] \tag{4}$$

[7] For further details see Brueckner, 2003.
[8] We may use any notion of nearness that makes theoretical sense, as long as it does not violate any of the assumptions about the connectivity matrix stated above. For alternative specifications of weight matrices see Anselin , (2002).

and by construction, this index ranges from 0 to 1, with *K* denoting the total amount of trade among countries *i* and *j*. In particular, if the proportion of trade in all activities is the same between the two regions, then $S_{ji} = 1$. The elements of trade connectivity matrix take the value of 0 if all the volume of trade of country *j* is in sectors for which country *i* has no volume of trade. Notice that this definition of similarity is symmetric in that $S_{ji} = S_{ij}$.

One interesting feature of the trade matrix is that more-opened countries have the bulk of their trade with large, wealthy, countries, which tends to demonstrate significant demand for outgoing calls. As a result, these countries that have greater openness and trade will tend to have a higher "connectivity lag" on average demand for telecommunications among their trading partners. Moreover, the volume of tourists per country may generate an alternative contiguity matrix (with similar definition as in (4)), which captures the significant human flows among different countries that affect the demand for telecommunications. Thus, trade and number of tourists may identify a very different set of pull factors than geographical proximity.

**B. Data**

Model specifications 1, 2 and 3 for telecommunications flows, presented above, are structurally similar to the regional spatial interaction models (Martínez and Araya 2000). However, the selected explanatory variables are significantly different involving trade, tourism and financial commonalities. The demand for international telecommunications is strongly affected by a large number of factors. These factors are presented as explanatory variables, and the annual data for them is obtained from Eurostat statistics, European Commission (2005), for the period 1999 to 2002 (25 member countries of the Union[9]).

Outgoing minutes of conversations, *m,* is the dependent variable of our analysis, measured in thousands of minutes. The *price* variable is the real average price (in Euros) per minute (including taxes) faced by customers, whereas the *gdp* variable denotes the real per capita GDP of each country measured in millions of Euros. Deflation of the nominal prices and per capita GDP is based on the consumer price index (CPI) for the corresponding years of our analysis. The variable *trade* shows the volume of trade (measured in millions of Euros) as an aggregate amount between European countries. It captures any economic transactions among different countries and represents significant economic activities.[10] The variable *tourists* refers to the number (measured in thousands) of tourists (European citizens) visited the European countries, whereas the variable *rd*

[9] The member countries are Austria, Belgium, Czech Republic, Denmark, Germany, Estonia, France, Finland, Greece, Great Britain, Spain, Sweden, Ireland, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Poland, Portugal, Slovenia, Slovakia. Period 1999 to 2002 is a significant period for the expansion process of the European Union including a substantial number from the above countries.

[10] Although spatial concentration of economic activities in European countries has been documented by Bottazzi and Peri (2003), few studies take into account spatial interdependence between them.

stands for research and development grants (measured in millions of Euros) for telecommunications, which are the funds for investments used in telecommunication sector per country. Lastly, the variable *lines*, which is the actual number of major telecommunications lines per country, provides an insight about country *i*'s infrastructure. Table 1 provides a descriptive analysis of all the variables of our model:

TABLE 1 HERE

Beside the information from Table 1, we provide at the Appendix of the paper Table A.1 and Table A.2. The first table presents the overall demand for telecommunications across countries in each year and a measure of the decay effects across countries over time. The second table presents all the spatial weights per country relative to all the others. Such information is particularly useful should we examine the degree of spatial similarity among any two European countries.

**III. Estimation results**

The presentation of results is based on the categorization of spatial effects. Section A covers a binary distance criterion, section B illustrates an inverse distance criterion and section C employs a k-neighbor criterion. Finally, a country specific effects analysis is incorporated at the last section.

**A. A binary distance measure of contiguity**

Telecommunication flows between countries may be likely to occur between nearby countries in a geographical sense. Hence, the first connectivity criterion is based on the geographical distance between European countries (Table 2). We use the minimum distance data to define countries as connected if they are within 500 km of one another.[11] This yields a binary connectivity matrix where each entry $w_{ij}$ is 1, if states $i$ and $j$ are within 500 km distance from each other and 0 otherwise. Each neighboring country is given equal weight in the row for country $i$.

TABLE 2 HERE

Table 2 reports the estimation results obtained by using *Specifications 1*, *2* and *3*. In particular, *Specification 1* has a spatial lag of dependent variable with a distance weight scheme ($k$), whereas *Specification 2* has both a distance weight scheme ($k_1$) and a trade (or tourism) weight scheme ($k_2$). Finally, *Specification 3* uses, in

[11] As suggested by the software of SpaceStat ®

addition to the spatial lags of *Specification 2*, both alternative weight schemes (trade and tourism) in respect to specific independent variables. Hence, an interaction weight component ($w_{i1}w_{i2}$) is created to estimate the impact of differentiated vectors of weight transformations. The interaction weight components capture the effects from countries with similar distance and trade (or tourism) characteristics, simultaneously[12]. An F-test shows that the spatial lags[13] per country are statistically significant in most estimated equations (Mátyás 1998).

Connectivity weights have important impact on the demand for telecommunications. The impact of those weights is denoted by the estimated elasticities of all the specifications of the model. Estimates of the spatial components (i.e., estimates of coefficients $k$ and $k_1$) are significant and noticeable. In fact, their values vary from 0.04 (tourism criterion) to 0.15 (trade criterion), indicating that the presence of spatial effects on both criteria captures significant patterns of intercommunications among European countries. For instance, if we increase neighboring[14] outgoing demand for telecommunications by 1%, the domestic demand will change by 0.12% (Table 2, 1st column; $k$). The magnitude of that elasticity is relative lower from the estimate of Guldmann (2000) which is 0.6%. However, the suggested spatial methodology used by Guldmann (2000) differs from the Anselin's (1988) methodology; used in this paper. Additionally, the impact (Table 2) of trade or tourism weigh schemes ($k_2$) varies from 0.02 to 0.12 where Guldman's (2000) results range between 0.09 to 0.52. Those estimates capture the omitted telecommunication bias in the models without any connectivity effects[15]. Given their significance, previous literature fails to account for their impact on the elasticity measures. Thus, their inclusion corrects the estimates of telecommunication elasticities. On the other hand, the estimates of the interaction components (i.e., estimates of coefficients $\rho_1$ and $\rho_2$) are all insignificant, no matter the criterion. Therefore, *Specification 3* does not provide any further insight and hence the simultaneous use of all weight specifications does not identify any significant pattern among the outgoing calls. A potential justification of the insignificance of interaction components is that spatial and economic components capture most of the omitted bias of the standard models[16].

[12] Spatial dependence is multidimensional, as suggested by Anselin (1988) and Brueckner (2003) . In our case, neighbors influence the behavior of their neighbors *and vice versa*. The multidimensional nature of spatial dependence leads to multiple implications. Interaction components aim to capture that multidimensionality but in terms of alternative forms of dependence. They provide additional insight as far as that dependence and do not capture the effects from spatial components. Their significance varies along with the definition of spatial weights and alternative types of weight. The paper shows that those components do affect the magnitude of the elasticities but their impact should be evaluated as part of the aggregate impact of all types of weights.

[13] For this purpose specifications (1, 2 and 3) are estimated and the *LM-ERR* and *LM-LAG* test statistics (Anselin and Bera 1998) are computed. Since the values of the *LM-LAG* test statistic are higher (lower *p*-value) than the *LM-ERR* test statistic, we conclude that the spatial lag formation is the proper formulation for our analysis.

[14] Neighboring refers to a group of countries based on the weight criterion.

[15] We computed all the standard models (specifications 1 and 3) without any connectivity effects (or interaction effects). However, space limitations restrict us from including OLS estimation of results. The differences, between those results and the one presented, are the resulted bias discussed in the paper.

[16] It should be emphasized that by including interaction components does not alter significantly the estimated results with connectivity effects.

The level of outgoing calls is affected[17] significantly by the *price* and by the volume of *trade* among the countries of our data set regardless of the model specification. Under any type of weight schemes, geographic, economic or social, the coefficients of *price* and *trade* have a negative[18] and positive impact on the number of calls, respectively. The latter conclusion follows the line of results of Garin-Munoz and Pérez-Amaral (1998) who find that the price elasticity and the volume of trade elasticity are 0.8 and 0.3, respectively. It is interesting to note that the absolute value of the coefficient of *price* is less than one, indicating that an elasticity of demand for international calls is inelastic.

The estimates of the coefficients of the remaining explanatory variables - number of *tourists*, *rd*, *gdp*, and number of *lines* - exhibit the expected sign (positive), but diverse impacts on the amount of outgoing calls. Their level of significance varies according the chosen specification and the connectivity criterion. The inclusion of *gdp* and number of *lines* in a spatially lagged formulation (i.e., *Specification 3*) considers the impact of "neighboring" countries not only from an infrastructure perspective (number of *lines,* through the coefficient of $\rho_1$) but also from an economic perspective (*gdp,* through the coefficient of $\rho_2$); although the estimates of the coefficients were not significant. In contrast to our results, Acton and Vogelsang (1992), analyzing the annual telephone traffic between the U.S. and 17 West European countries over the period 1979-1986, indicate that neighboring GDP variables range from 0.11 and 0.27.

### B. Inverse distance measure of contiguity

Our second specification of weight matrices uses the inverse distance criterion to account for the geographical distance between European countries. The inverse distance-based approach places less importance to all countries *j* that are far away from country *i*. In particular, the elements $w_{ij}$, of the inverse distance-based weight matrix are computed as: $w_{ij} = (d_{ij})^{-2}$, where *d* denotes distance between countries *i* and *j*, and are defined as a decaying function in space. The current specification of weights provides significant insight about the role of distance in telecommunications.

Table 3 presents similar results to those obtained by previous weight specifications. First, spatial effects can be detected only using *Specifications 1* and *2* since the estimates of the interaction components are not

[17] Actually, we take into account the endogeneity of both prices and other countries demand by using Instrumental Variable (IV) method (Brueckner 2003). In spatial econometrics it is generally accepted to use as instruments neighboring (spatial lags) explanatory variables (see Brueckner (2003) for the theory, and Brett and Pinkse ( 2000) for a recent application).

[18] Demand in neighboring countries is deemed to be positively correlated with demand in the primary country, so to get the apparent negative bias on price that we see, it must be that demand in neighboring countries is negatively correlated with own price. Perhaps prices are correlated across countries, so an increase in own price is related to an increase in a neighboring country's price, resulting in less demand in the neighboring country. We are grateful to the referee for this thoughtful comment.

significant. Only the estimate of the interaction component (coefficient of GDP, $\rho_2$) is significant. The latter result verifies the existence of regional economic clusters, since neighboring GDP for any two countries affect the demand for calls. In contrast, no evidence is found for the relationship among outgoing calls of country *i* and neighboring infrastructure from countries *j* (coefficient $\rho_1$). The latter result is robust to any type of weight criteria and in line with Cameron and White (1990). They use a sample of 26,672 long-distance calls originating from British Columbia, and they find that call duration decreases with distance (a result similar to Pacey's 1983).

TABLE 3 HERE

The remaining estimates follow a similar pattern with the results of Table 2. Their magnitude and their significance do not present any serious alterations, indicating that the robustness of these results is not affected either by the definition of economic or social weight specifications or by the nature of geographic weights. In fact, even the absolute magnitude of the elasticities of demand does not change.

**C. *K*-neighbors measure of contiguity (*k* = 6)**

The *k*-neighbors criterion is based on a predetermined number (*k*) of countries that are geographically close to country *i*. The choice of the exact number *k* is based on the number of geographical observations and their locational characteristics. Although we use *k* = 6 (Table 4), *Specifications 1*, *2* and *3* have also been estimated under alternative definitions of *k*, i.e., *k* = 4 and 8, but the results did not present any significant changes.

Alternative clustering procedure is implemented by Fischer et al. (1994) with Austrian regional telephone flows. They conclude that the strength of the interaction among groups of regions is an important determinant for the demand for telecommunication. Their result is in accordance with the results using predetermined number of countries to examine telephone flows. However, the innovation of our results relative to the results of Fischer et al. (1994) is that they do not account for multidimensional omitted bias but only for bias originated from social interactions.

The most interesting result is that the predetermined number of neighbors affects the significance of cross connectivity effects. The latter criterion allows one to examine the elasticity of telecommunication industry at a 'neighborhood' level, offering significant insight for potential clusters at telecommunication flows. As it is shown (Table 4), *Specification 3* has now significant estimates of the interaction components under both trade and tourism criteria ranging their values from 0.03 (tourism criterion) to 0.07 (trade criterion). The magnitudes of those elasticities should not be evaluated individually but in relation to the spatial and economic (trade/tourism) components[19]. An example refers to southern Mediterranean countries where the volume of outgoing calls is affected by the group of countries located in the area. The geographic cluster coincides with the economic and social cluster and indeed this result verifies that countries with significant amount of tourists do affect the demand for outgoing calls. The latter results are innovative in the existing literature and provide an additional perspective.

Table 4 presents estimates which are very similar to those estimates previously obtained. The main difference refers to the magnitude of the elasticity of demand for international telecommunications which has slightly changed and it is elastic; only though for *Specification 1*, whereas for all other specifications remains inelastic. The estimates of the coefficients of the remaining explanatory variables**,** number of *tourists*, *rd*, *gdp*, and number of *lines*, have all the expected sign and their magnitude does not differ significantly from the previously obtained results. Karikari and Gyimah-Brempong (1999), using traffic data between the U.S. and 45 African countries over the 1992-1996 period, implement a simultaneous equations approach and regress the number of calls in one direction on the lagged traffic in this direction, the return traffic, the price of an outgoing call, the GDP per capita, the volume of trade, the differential in outgoing and incoming prices, and the product of the number of households. The latter results are in line with our estimates.

In general, the results in Table 4 are more difficult to be interpreted. The positive and highly significant coefficients of the interaction terms point out the complex and synergistic effect of financial or infrastructure commonalities. Estimated results suggest that clusters of countries with similar financial and social standards encourage the demand for telecommunications. Consequently, there are connectivity structure effects in international telecommunications, of both competitive and agglomerative nature.

TABLE 4 HERE

We further investigate the spatial effects in telecommunications by examining the relationship between country-specific effects and location decay effects. For this purpose, we use equation (3) to examine country specific decay effect through the use of dummy variables. Actually, we evaluate it for each country separately and we plot the bundle of trade (Figure 1) - or tourism (Figure 2) - weights along with the spatial (decay) weights. Hence, we plot the coefficient of spatial, trade, and tourism components per country, resulting in 25

[19] Please refer to footnote 15.

points of observation (number of European countries), to get the individual country specific effects. The results are shown in Figures 1 and 2 with respect to trade and tourism effects.

Figure 1 reveals a strong relationship between the existence of geographical interconnections (location decay effect) and the importance of trade flows (country-specific trade effects) which indicates that geographical clusters play an important role in trade activities. This may be attributed to three factors: First, countries with several trade partners and important volume of trade (i.e., Germany and Italy) are more likely to present high trade effects and high degree of clustering, a result which is in line with Krugman (1991). Second, locational concentrations may result from cultural commonalities which encourage extended financial activities. Thus, countries which present low trade activities (i.e., Estonia and Latvia) normally exhibit insignificant locational decay effect.

FIGURE 1 HERE

FIGURE 2 HERE

Figure 2 illustrates the relationship between the existence of geographical interconnections (location decay effect) and tourism flows (country-specific tourism effects) across the European Union. For instance, Greece and Italy are characteristic cases of tourism and geographical externalities, since significant flows of visitors are partially facilitated by the geographical proximity of those countries. These countries present similar values of country-specific tourism effects and similar values of locational decay effect (Figure 2). In contrast, Hungary and Spain exhibit significantly different values of both country-specific tourism effects and locational decay effect.

**IV. Concluding Remarks**

In this study, we examine demand models for telecommunications for European countries in the context of spatial econometrics. In fact, because of the geographic heritage of these models, their primary application is to incorporate physical notions of space (distance) into the estimation procedure and to argue that geographically nearby units are linked together. Telecommunications in any country depend on the telecommunications in proximate countries or on similar countries in terms of economic or social characteristics. Such types of interdependences have been largely ignored by the empirical telecommunication literature with only a couple recent papers accounting for such issues in their estimation. This paper manages to incorporate them in its approximation using data from the European Union. Actually, geographic proximity (spatial effects) has a significant role since it allows for the study of agglomeration spillovers, trade interdependencies (economic effects) emphasize the existence of strong financial relationships across European countries and considerable tourism flows (social effects) show a pattern of human migration across Europe. The latter effects are essential for the analysis of telecommunication models.

The most important aspect in spatial econometrics is the definition of the connectivity matrix. We defined the distance weight matrices in three different ways: i.e., a) a binary distance measure of contiguity, b) an inverse distance measure of contiguity and c) a $k$-neighbors measure of contiguity for $k = 6$, and we also considered two alternative weight matrices: an economic weight matrix using the volume of trade and a social weight matrix using the flow of tourist to incorporate the economic and social effects. This study finds evidence of important connectivity effects and the results are robust across to different specifications of connectivity matrices. Moreover, they indicate the importance of trade and tourism for telecommunications services in any country.

Geographic and other spatial characteristics may have a different impact on internet networks than on mobile or wire line communications networks. The rise of these alternative and competing networks presents a potential problem for our approach. For instance in US, there has been a significant decline in measured or metered telecom service - which is being replaced first by flat rates for local and toll calls, and later by bundled service packages – masking the per unit call price. Thus, the emergence and the rapid growth of these alternative networks and payment plans should be evaluated on a parallel basis since the nature of this sector of telecommunications is different from the one studied in this paper.

Presented results are innovative for the existing literature of telecommunications. Omitted variable bias is limited in telecommunications models with spatial, economic and social connectivity effects. On the other hand, it is worth noting that we find significant omitted telecommunications variable bias under economic or social criteria. This point is particularly applicable to the few previous studies of spatial effects in empirical telecommunications models.

# Appendix

Table A.1 Aggregate demand for telecommunications and decay rates

| Country | Aggregate demand | | | | Decay rates | | | |
|---|---|---|---|---|---|---|---|---|
| | *1999* | *2000* | *2001* | *2002* | *1999* | *2000* | *2001* | *2002* |
| Austria | 2517.8 | 2648.4 | 2356.4 | 2377.5 | 0.15 | 0.14 | 0.14 | 0.15 |
| Belgium | 1249.8 | 1543.1 | 1767.5 | 1865.4 | 0.18 | 0.17 | 0.19 | 0.21 |
| Czech Rep. | 454.5 | 359.9 | 321.7 | 315.6 | 0.35 | 0.39 | 0.41 | 0.38 |
| Cyprus | 163.0 | 195.6 | 220.2 | 255.8 | 0.15 | 0.17 | 0.17 | 0.18 |
| Denmark | 655.8 | 700.5 | 740.0 | 656.4 | 0.01 | 0.02 | 0.02 | 0.02 |
| Germany | 7900.0 | 9223.0 | 8386.0 | 9474.0 | 0.16 | 0.18 | 0.17 | 0.19 |
| Estonia | 73.4 | 75.5 | 48.2 | 78.2 | 0.31 | 0.32 | 0.36 | 0.34 |
| France | 3200.0 | 3487.6 | 3675.4 | 3781.9 | 0.05 | 0.06 | 0.06 | 0.05 |
| Finland | 588.9 | 700.0 | 456.7 | 567.9 | 0.28 | 0.32 | 0.33 | 0.32 |
| Great Britain | 7077.5 | 7751.2 | 7935.1 | 8356.4 | 0.16 | 0.17 | 0.18 | 0.19 |
| Greece | 728.7 | 724.6 | 718.5 | 1123.1 | 0.19 | 0.21 | 0.22 | 0.21 |
| Hungary | 131.1 | 134.1 | 132.7 | 139.2 | 0.16 | 0.20 | 0.21 | 0.20 |
| Spain | 1956.0 | 2547.0 | 3178.6 | 3297.8 | 0.12 | 0.13 | 0.14 | 0.15 |
| Sweden | 1516.0 | 1642.0 | 1360.0 | 1363.0 | 0.27 | 0.30 | 0.31 | 0.31 |
| Ireland | 1015.0 | 1639.0 | 1543.7 | 1774.2 | 0.16 | 0.18 | 0.18 | 0.19 |
| Italy | 3523.0 | 3849.0 | 5021.4 | 5788.3 | 0.09 | 0.10 | 0.11 | 0.10 |
| Latvia | 56.3 | 63.2 | 61.1 | 63.0 | 0.26 | 0.29 | 0.30 | 0.28 |
| Lithuania | 59.9 | 64.9 | 67.1 | 81.3 | 0.03 | 0.03 | 0.03 | 0.04 |
| Luxembourg | 319.1 | 366.3 | 394.6 | 366.0 | 0.01 | 0.01 | 0.01 | 0.02 |
| Malta | 39.0 | 25.2 | 28.7 | 29.5 | 0.15 | 0.17 | 0.17 | 0.16 |
| Netherlands | 2150.0 | 2500.0 | 2600.0 | 2877.6 | 0.07 | 0.08 | 0.08 | 0.07 |
| Poland | 624.2 | 663.7 | 706.7 | 752.9 | 0.24 | 0.26 | 0.28 | 0.29 |
| Portugal | 540.0 | 511.0 | 550.4 | 541.0 | 0.18 | 0.20 | 0.21 | 0.22 |
| Slovenia | 181.7 | 220.7 | 249.2 | 106.7 | 0.15 | 0.17 | 0.17 | 0.18 |
| Slovakia | 162.7 | 162.2 | 172.5 | 214.9 | 0.14 | 0.15 | 0.16 | 0.15 |

Note: Aggregate demand shows the total minutes of demand for international outgoing calls where decay rates are estimated based on equation (5) and by using data from each country as suggested in section 4.4.

Table A.2 Spatial weights

| Country | Austria | Belgium | Czech Republic | Cyprus | Denmark | Germany | Estonia | France | Finland | Great Britain | Greece | Hungary | Spain | Sweden | Ireland | Italy | Latvia | Lithuania | Luxembourg | Malta | Netherlands | Poland | Portugal | Slovenia | Slovakia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Austria | 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| Belgium | 0.4 | 0 | | | | | | | | | | | | | | | | | | | | | | | |
| Czech Rep. | 0.9 | 0.7 | 0 | | | | | | | | | | | | | | | | | | | | | | |
| Cyprus | 0.2 | 0.1 | 0.2 | 0 | | | | | | | | | | | | | | | | | | | | | |
| Denmark | 0.3 | 0.7 | 0.4 | 0.1 | 0 | | | | | | | | | | | | | | | | | | | | |
| Germany | 0.9 | 0.9 | 0.9 | 0.1 | 0.9 | 0 | | | | | | | | | | | | | | | | | | | |
| Estonia | 0.6 | 0.5 | 0.6 | 0.1 | 0.8 | 0.8 | 0 | | | | | | | | | | | | | | | | | | |
| France | 0.8 | 0.9 | 0.8 | 0.1 | 0.6 | 0.9 | 0.2 | 0 | | | | | | | | | | | | | | | | | |
| Finland | 0.3 | 0.5 | 0.4 | 0.1 | 0.8 | 0.8 | 0.9 | 0.4 | 0 | | | | | | | | | | | | | | | | |
| Great Britain | 0.3 | 0.9 | 0.6 | 0.1 | 0.8 | 0.7 | 0.6 | 0.8 | 0.7 | 0 | | | | | | | | | | | | | | | |
| Greece | 0.5 | 0.3 | 0.6 | 0.9 | 0.2 | 0.4 | 0.1 | 0.6 | 0.1 | 0.1 | 0 | | | | | | | | | | | | | | |
| Hungary | 0.9 | 0.7 | 0.8 | 0.1 | 0.6 | 0.8 | 0.6 | 0.6 | 0.4 | 0.3 | 0.6 | 0 | | | | | | | | | | | | | |
| Spain | 0.8 | 0.8 | 0.6 | 0.1 | 0.6 | 0.7 | 0.1 | 0.9 | 0.1 | 0.7 | 0.3 | 0.5 | 0 | | | | | | | | | | | | |
| Sweden | 0.3 | 0.5 | 0.4 | 0.1 | 0.8 | 0.8 | 0.9 | 0.4 | 0.9 | 0.7 | 0.2 | 0.4 | 0.3 | 0 | | | | | | | | | | | |
| Ireland | 0.3 | 0.8 | 0.6 | 0.1 | 0.8 | 0.7 | 0.6 | 0.8 | 0.7 | 0.9 | 0.1 | 0.2 | 0.6 | 0.4 | 0 | | | | | | | | | | |
| Italy | 0.8 | 0.7 | 0.7 | 0.2 | 0.5 | 0.8 | 0.3 | 0.9 | 0.4 | 0.6 | 0.9 | 0.6 | 0.8 | 0.4 | 0.2 | 0 | | | | | | | | | |
| Latvia | 0.3 | 0.5 | 0.4 | 0.1 | 0.8 | 0.8 | 0.9 | 0.3 | 0.8 | 0.6 | 0.2 | 0.3 | 0.2 | 0.7 | 0.4 | 0.2 | 0 | | | | | | | | |
| Lithuania | 0.3 | 0.5 | 0.4 | 0.1 | 0.8 | 0.8 | 0.9 | 0.3 | 0.8 | 0.6 | 0.2 | 0.3 | 0.2 | 0.7 | 0.4 | 0.2 | 0.9 | 0 | | | | | | | |
| Luxembourg | 0.8 | 0.9 | 0.8 | 0.1 | 0.6 | 0.9 | 0.2 | 0.9 | 0.6 | 0.6 | 0.2 | 0.6 | 0..6 | 0.7 | 0.6 | 0.6 | 0.7 | 0.6 | 0 | | | | | | |
| Malta | 0.8 | 0.7 | 0.7 | 0.2 | 0.5 | 0.8 | 0.3 | 0.9 | 0.4 | 0.6 | 0.9 | 0.6 | 0.8 | 0.4 | 0.2 | 0.9 | 0.4 | 0.1 | 0.3 | 0 | | | | | |
| Netherlands | 0.8 | 0.9 | 0.8 | 0.1 | 0.6 | 0.9 | 0.2 | 0.9 | 0.6 | 0.6 | 0.2 | 0.6 | 0..6 | 0.7 | 0.6 | 0.6 | 0.7 | 0.6 | 0.9 | 0.2 | 0 | | | | |
| Poland | 0.3 | 0.5 | 0.4 | 0.1 | 0.8 | 0.8 | 0.7 | 0.3 | 0.8 | 0.6 | 0.2 | 0.3 | 0.2 | 0.7 | 0.4 | 0.2 | 0.8 | 0.9 | 0.8 | 0.4 | 0.7 | 0 | | | |
| Portugal | 0.7 | 0.7 | 0.5 | 0.1 | 0.5 | 0.5 | 0.1 | 0.8 | 0.1 | 0.6 | 0.2 | 0.2 | 0.9 | 0.2 | 0.1 | 0.4 | 0.1 | 0.1 | 0.4 | 0.3 | 0.5 | 0.3 | 0 | | |
| Slovenia | 0.9 | 0.7 | 0.7 | 0.1 | 0.5 | 0.8 | 0.3 | 0.9 | 0.4 | 0.6 | 0.9 | 0.9 | 0.8 | 0.4 | 0.2 | 0.9 | 0.5 | 0.5 | 0.6 | 0.7 | 0.7 | 0.8 | 0.4 | 0 | |
| Slovakia | 0.9 | 0.7 | 0.9 | 0.1 | 0.5 | 0.8 | 0.3 | 0.9 | 0.4 | 0.6 | 0.9 | 0.9 | 0.8 | 0.4 | 0.2 | 0.9 | 0.5 | 0.5 | 0.6 | 0.7 | 0.9 | 0.8 | 0.4 | 0.8 | 0 |

Note: Estimation of the non-standardized weights is done with the SpaceStat software.

## References


Acton, Jan Paul and Ingo Vogelsang (1992), "Telephone demand over the Atlantic: evidence from country-pair data", *Journal of Industrial Economics* **40:** 1-19.

Agiakloglou, Christos and Dimitris Yannelis (2005), "Estimation of Price Elasticities for International Telecommunications Demand", *International Advances in Economic Research* **12:** 131-137.

Anselin, Luc (1988), *Spatial Econometrics: Methods and Models*, Kluwer Press, Boston.

Anselin, Luc (2002), "Under the hood: Issues in the specification and interpretation of spatial regression models", *Agricultural Economics* **27:** 247-267.

Anselin, Luc and Annil Bera (1998), *Handbook of Applied Economic Statistics*, New York, Marcel Dekker Press.

Armstrong, Mark (1998), "Network Interconnection in Telecommunications", *The Economic Journal* **108:** 545-564.

Bewley, Ronald and Denzil Fiebig (1988), "Estimation of price elasticities for an international telephone demand model", *Journal of Industrial Economics* **36:** 393-409.

Blonigen, Bruce, Ronald Davies, Glen Waddell, and Helen Naughton (2006), "FDI in space: Spatial autoregressive relationships in foreign direct investment", *European Economic Review* **51:** 1303–1325

Bottazzi, Laura, and Giovanni Peri (2003), "Innovation and Spillovers in Regions: Evidence from European Patent Data", *European Economic Review* **47(4):** 687-710.

Brueckner, Jan (2003), "Strategic interaction among governments: An overview of empirical studies", *International Regional Science Review* **26:** 175-188.

Brett, Creg, and John Pinkse (2000) 'The determinants of municipal tax rates in British Columbia,' *Canadian Journal of Economics* **33:** 695-714

Cameron, Trudy and Keith White (1990), *Generalized Gamma Family Regression Models for Long Distance Call Durations. In Telecommunications Demand Modeling – An Integrated View*, Amsterdam: Elsevier Science Publishers.

Cliff, Andrew and K.eithOrd (1981), *Spatial Process. Models and Applications*, London: Pion Limited.

Christaller, Walter (1966), *Central Places in Southern Germany*, Englewood Cliffs, NJ, Prentice Hall.

Cressie, Noel (1993), *Statistics for Spatial Data*, New York, Wiley.

De Fontenay, Alex and Lee Marshall (1983), *B.C./Alberta Long Distance Calling. In Economic Analysis of Telecommunications: Theory and Applications*, Amsterdam: Elsevier Science Publishers.

European Commission (2005), The European Business and Innovation Centres (BICs), Directorate – General for research, European Commission.

Fischer, Manfred and Sucharita Gopal (1994), "Artificial Neural Networks: A New Approach to Modeling Interregional Telecommunication Flows", Journal of Regional Science **34( 4):** 503-527.

Garin Munoz and Perez Amaral (1998), "Econometric modeling of Spanish very long distance international calling", *Information Economics and Policy* **10:** 237-252.

Gasmi, Farid, Jean-Jacques Laffont and Walter Sharkey (1999), "Empirical evaluation of regulatory regimes in local telecommunications markets", *Journal of Economics and Management Strategy* **8:** 61-93.

Gatto, Joseph, Harry Kelejian and Scott Stephan (1988) "Stochastic Generalization of Demand Systems with an Application to Telecommunications", *Information Economics and Policy* **3:** 283-309.

Green, Howard (1955), "Hinterland Boundaries of New York City and Boston in Southern New England", *Economic Geography* **31**, 283-300.

Gruber Harry and Frank Verboven (2001), "The diffusion of mobile telecommunications services in the European Union", *European Economic Review* **45:** 577-588.

Guldmann Jean-Michel (2000), Spatial Interaction Models of International Telecommunication flows, unpublished manuscript, Ohio State University.

Karikari, John and Kwabena Gyimah-Brempong (1999), "Demand for International Telephone Services Between U.S. and Africa", *Information Economics and Policy* **11:** 407-435.

Kelejian, Harry and Ingmar Prucha (2005), Estimation of Spatially Autoregressive Models with Spatially Correlated Error Components from Panel Data, University of Maryland, mimeo.

Kelejian, Harry and Ingmar Prucha (1998), "A generalized spatial two-stage least squares procedure for estimating a spatial autoregressive model with autoregressive disturbances", *Journal of Real Estate Finance and Economics* **17:** 99-121.

Kiss, Ferenc and Bernard Lefebvre (1987), "Econometric models of telecommunications: a survey", *Revue Économique* **2:** 307–374.

Krugman Paul (1991), *Geography and Trade*, MIT Press, Cambridge MA.

Lacombe, Donald (2004), "Does Econometric Methodology Matter? An Analysis of Public Policy Using Spatial Econometric Techniques", *Geographical Analysis* **3:** 156 - 173.

Laffort, Jean-Jacques and Jean Tirole (1993), *A Theory of Incentives in Procurement and Regulation*, MIT Press, London.

Laffort, Jean-Jacques and Jean Tirole (2000), *Competition in Telecommunications*, MIT Press, London.

Madden, Gary and Scott Savage (2000), "Market structure, competition and pricing in United States international telephone services markets", *Review of Economics and Statistics* **82:** 291-296.

Martínez Francisco and Claudio Araya (2000), "A note on trip benefits in spatial interaction models", *Journal of Regional Science* **40:** 789 – 796.

Mátyás, Laszlo (1998), "The Gravity Model: Some Econometric Considerations", *The World Economy*, **21:** 397-401.

Moran, Patrick (1950), "Notes on continuous stochastic phenomena", *Biometrika* **37:** 17-23.

Pacey, Patricia (1983), "Long Distance Demand: A Point-to-Point Model", *Southern Economic Journal* **49:** 1094-1107.

Park, Rolla, Bruce Wetzel and Bridger Mitchell (1983), "Price elasticities for local telephone calls", *Econometrica* **51:** 1699-1730.

Parks, Richard, (1967), "Efficient Estimation of a System of Regression Equations When Disturbances Are Both Serially and Contemporaneously Correlated", *Journal of the American Statistical Association* **62:** 500–509.

Sandbach, Jonathan (1996), "International telephone traffic, call-back and policy implications", *Telecommunications Policy* **20:** 507-515.

Wright, Julian (1999), "International telecommunications, settlement rates and the FCC", *Journal of Regulatory Economics* **15:** 267-291.

Zucker, Lynne, Michael Darby and Jeff Armstrong (1998), "Geographically localized knowledge: Spillovers or Markets", *Economic Inquiry* **36:** 65-86.

**Table 1. Descriptive Statistics**

| Variable | Mean | Minimum | Maximum | Standard Deviation |
|---|---|---|---|---|
| *Outgoing minutes* | 1676 | 25 | 9474 | 2306 |
| *price* | 1.05 | 0.16 | 2.79 | 0.56 |
| *trade* | 945 | 6754 | 489896 | 45789.11 |
| *tourists* | 8870.32 | 12 | 552 | 121.57 |
| *rd* | 1.43 | 0.22 | 4.27 | 0.95 |
| *gdp* | 53852.61 | 3065.23 | 26008.13 | 5776.44 |
| *line* | 48.3 | 25 | 76 | 12.61 |

**Table 2. Estimation results under predefined distance proximity**

| Variables | Specification 1 | Specification 2 | Specification 3 | Specification 1 | Specification 2 | Specification 3 |
|---|---|---|---|---|---|---|
| | **Spatial and trade weights** | | | **Spatial and tourism weights** | | |
| *price* | -0.82*** (22.1) | -0.63*** (16.2) | -0.58*** (12.1) | -0.96*** (10.91) | -0.71** (2.37) | -0.39*** (3.71) |
| *trade* | 0.14*** (16.75) | 0.09* (1.89) | 0.12** (3.11) | 0.11*** (7.72) | 0.08* (1.89) | 0.06*** (4.18) |
| *tourists* | 0.05*** (4.11) | 0.07** (2.96) | 0.06** (3.15) | 0.03*** (3.88) | 0.02* (1.83) | 0.09** (2.23) |
| *rd* | 0.55 (1.01) | 0.49 (1.15) | 0.39 (0.97) | 1.34 (0.42) | 0.22* (2.11) | 0.41* (2.89) |
| *gdp* | 0.09** (2.71) | 0.12* (2.51) | | 0.11*** (8.93) | 0.19* (2.11) | |
| *line* | 0.91 (0.88) | 0.43 (1.51) | | 0.16* (2.01) | 0.21* (2.34) | |
| **Spatial Component** | | | | | | |
| *k* | 0.12*** (7.72) | | | 0.05*** (3.23) | | |
| $k_1$ | | 0.15*** (8.91) | 0.09*** (7.82) | | 0.06** (3.01) | 0.04** (2.97) |
| **Trade/Tourism Component** | | | | | | |
| $k_2$ | | 0.12* (1.96) | 0.07** (2.29) | | 0.02 (0.67) | 0.02* (1.98) |
| **Interaction Component** | | | | | | |
| $\rho_1$ | | | 0.01 (0.44) | | | 0.02 (0.79) |
| $\rho_2$ | | | 0.05 (0.31) | | | 0.01 (0.05) |
| Country dummies | No | Yes | Yes | No | Yes | Yes |
| $R^2$adjusted | 0.68 | 0.71 | 0.72 | 0.62 | 0.68 | 0.69 |
| F test | 9.17 | 9.64 | 10.01 | 9.36 | 9.75 | 10.85 |
| Chi square test | 64.27 | 65.16 | 68.11 | 65.52 | 68.79 | 66.75 |

*Note*: Numbers in parentheses are t statistics where *, **, *** are 10%, 5% and 1% respectively.

**Table 3. Estimation results under inverse distance proximity**

| Variables | Specification 1 | Specification 2 | Specification 3 | Specification 1 | Specification 2 | Specification 3 |
|---|---|---|---|---|---|---|
| | **Spatial and trade weights** | | | **Spatial and tourism weights** | | |
| *price* | -0.71*** | -0.58** | -0.48*** | -0.96*** | -0.68** | -0.34*** |
| | (19.23) | (3.01) | (10.09) | (10.91) | (2.67) | (3.23) |
| *trade* | 0.12*** | 0.10** | 0.09*** | 0.11*** | 0.07* | 0.05*** |
| | (14.57) | (2.39) | (7.55) | (7.72) | (1.95) | (3.64) |
| *tourists* | 0.04*** | 0.06* | 0.05*** | 0.02*** | 0.02 | 0.08 |
| | (3.58) | (1.94) | (3.68) | (3.14) | (0.97) | (1.05) |
| *rd* | 0.48 | 0.39 | 0.27 | 1.17 | 0.19 | 0.36** |
| | (0.88) | (0.67) | (1.64) | (0.37) | (0.84) | (2.51) |
| *gdp* | 0.08** | 0.11* | | 0.1*** | 0.16** | |
| | (6.71) | (1.95) | | (7.77) | (2.33) | |
| *line* | 0.79 | 0.55 | | 0.14* | 0.19* | |
| | (0.77) | (0.39) | | (1.75) | (2.01) | |
| **Spatial Component** | | | | | | |
| $k$ | 0.1*** | | | 0.04** | | |
| | (10.2) | | | (2.81) | | |
| $k_1$ | | 0.12*** | 0.08*** | | 0.05** | 0.03** |
| | | (6.01) | (6.94) | | (2.18) | (3.29) |
| **Trade/Tourism Component** | | | | | | |
| $k_2$ | | 0.07* | 0.06** | | 0.02 | 0.02* |
| | | (1.88) | (2.55) | | (0.91) | (2.06) |
| **Interaction Component** | | | | | | |
| $\rho_1$ | | | 0.01 | | | 0.02** |
| | | | (0.31) | | | (2.65) |
| $\rho_2$ | | | 0.04 | | | 0.01 |
| | | | (0.17) | | | (0.11) |
| Country dummies | No | Yes | Yes | No | Yes | Yes |
| $R^2$adjusted | 0.58 | 0.63 | 0.65 | 0.55 | 0.59 | 0.63 |
| F test | 8.11 | 8.92 | 9.11 | 8.74 | 8.36 | 9.77 |
| Chi square test | 75.08 | 73.72 | 70.92 | 71.11 | 70.96 | 73.41 |

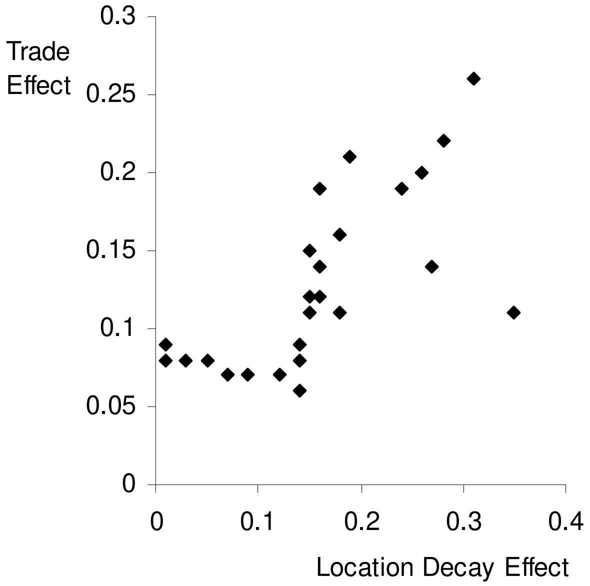
*Note*: Numbers in parentheses are t statistics where *, **, *** are 10%, 5% and 1% respectively.

**Table 4. Estimation results under *k*-neighbors proximity**

| Variables | Specification 1 | Specification 2 | Specification 3 | Specification 1 | Specification 2 | Specification 3 |
|---|---|---|---|---|---|---|
| | Spatial and trade weights | | | Spatial and tourism weights | | |
| *price* | -1.07*** | -0.84*** | -0.79*** | -1.26*** | -0.85*** | -0.63** |
| | (28.95) | (15.19) | (11.03) | (14.29) | (6.83) | (2.54) |
| *trade* | 0.18*** | 0.14** | 0.17** | 0.14*** | 0.11** | 0.09* |
| | (21.94) | (2.58) | (2.44) | (10.11) | (2.45) | (1.99) |
| *tourists* | 0.07*** | 0.11** | 0.09* | 0.03*** | 0.05 | 0.11 |
| | (5.34) | (2.52) | (2.04) | (4.11) | (1.05) | (1.1) |
| *rd* | 0.72 | 0.63* | 0.48* | 1.53 | 0.24* | 0.31* |
| | (1.32) | (2.01) | (2.11) | (0.48) | (2.03) | (2.15) |
| *gdp* | 0.12*** | 0.19** | | 0.14*** | 0.23** | |
| | (10.1) | (2.53) | | (10.18) | (2.33) | |
| *line* | 1.19 | 0.72* | | 0.18** | 0.14* | |
| | (1.15) | (2.03) | | (2.29) | (1.91) | |
| **Spatial Component** | | | | | | |
| $k$ | 0.13*** | | | 0.16*** | | |
| | (13.36) | | | (15.35) | | |
| $k_1$ | | 0.16** | 0.14** | | 0.07** | 0.04* |
| | | (2.67) | (2.93) | | (2.61) | (1.84) |
| **Trade/Tourism Component** | | | | | | |
| $k_2$ | | 0.11*** | 0.09*** | | 0.03 | 0.03* |
| | | (8.01) | (6.84) | | (0.54) | (1.93) |
| **Interaction Component** | | | | | | |
| $\rho_1$ | | | 0.04** | | | 0.05** |
| | | | (2.61) | | | (3.02) |
| $\rho_2$ | | | 0.07* | | | 0.03* |
| | | | (2.07) | | | (1.99) |
| Country dummies | No | Yes | Yes | No | Yes | Yes |
| $R^2$adjusted | 0.57 | 0.58 | 0.59 | 0.61 | 0.68 | 0.71 |
| F test | 8.86 | 9.17 | 9.89 | 8.42 | 9.59 | 9.22 |
| Chi square test | 88.62 | 93.64 | 94.77 | 86.23 | 90.12 | 93.68 |

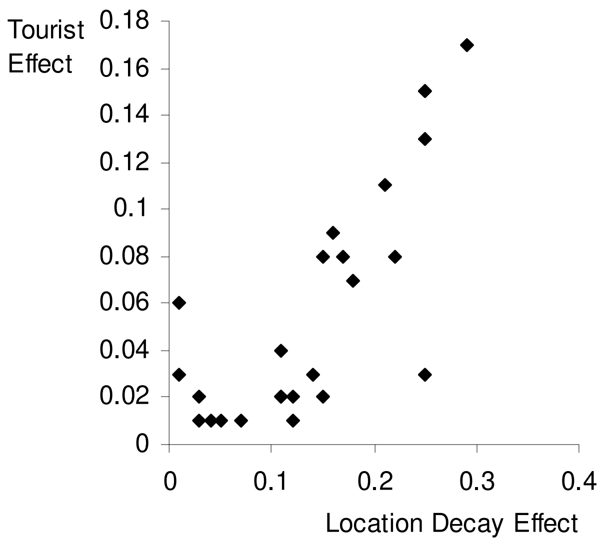
*Note*: Numbers in parentheses are t statistics where *, **, *** are 10%, 5% and 1% respectively.

**Figure 1. Estimated country-specific trade effects and location decay effect**




*Note*: European countries are represented by dots.

**Figure 2. Estimated country-specific tourism effects and location decay effect**




*Note*: European countries are represented by dots.