COMPETING DESTINATIONS AND INTERVENING OPPORTUNITIES INTERACTION MODELS OF INTER-CITY TELECOMMUNICATION FLOWS†

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ABSTRACT

This research makes use of a large sample of individual telephone calls between local exchanges (cities, villages) within a U.S. region. The interlocational flows (number of conversation minutes) are analyzed by estimating, in a simultaneous equation framework, spatial interaction models that account for (1) the role of the spatial structure, which reflects the competition and agglomeration effects that take place among the flow destinations, and (2) the role of the reverse flows, which reflect the process of information creation necessary to complete economic and social transactions. A particular focus is set on Fotheringham's competing destinations model and Stouffer's intervening opportunities model. The implications of the results are discussed and areas for further research are outlined.

I. INTRODUCTION

While telecommunication circuits are deemed the electronic highways of the modern economy, little is known on the flows they carry and the fundamental determinants of these flows (Staple and Mullins, 1989). This scarcity of empirical research has often been blamed on the difficulty in obtaining proprietary data from telephone companies (Taylor, 1980, 1994), and this situation is likely to worsen with the accelerating worldwide trend towards deregulation and competition in all telecommunication markets. Abler (1991) also notes the relative failure of geography to analyze telecommunication flows.

The purpose of this paper is to increase our understanding of the spatial structure of point-to-point telecommunication flows, using a very rich telephone calls data base provided by a U.S. telephone company and comprehensively covering a whole region. The focus is set on extending earlier spatial interaction models to account for the effects of the spatial structure on the pattern of flows, and various formulations of competing destinations and intervening opportunities factors are considered and empirically tested through extensive sensitivity analyses.

The remainder of the paper is organized as follows. Section II consists in a review of the relevant literature. The conceptual framework is presented in Section III. The data sources, functional specification, and empirical results are reviewed and discussed in Section IV. Conclusions and areas for further research are outlined in Section V.

II. LITERATURE REVIEW

This review is restricted to gravity-type models of point-to-point telecommunication flows. For extensive reviews of non-spatialized models, see Taylor (1980, 1994).

Geographical studies emphasize the effects of distance and place size/centrality. The earliest study of intercity telephone flows appears to be that of Hammer and Iklé (1957), who regress the total number of telephone calls, in both directions, between pairs of cities with the airline distance and the respective numbers of subscribers. A similar gravity model is estimated by Leinbach (1973), using telephone flow data for West Malaysia and regressing the number of intercity messages on distance and the modernization scores of the origin and destination cities, as obtained from a principal component analysis of various socio-economic data. In addition, he estimates similar models for 16 originating exchanges separately, and then demonstrates a significant relationship between the distance coefficient and the distance of the exchange from a modernization core located close to the capital, Kuala Lumpur. While he finds no relationship between the weight of the destination mass and the exchange size and location, Leinbach provides convincing evidence of the influence of exchange location (i.e., spatial structure) on the effect of distance upon telecommunication flows, the closer the exchange to the core the lesser the effect of distance. Hirst (1975), using telephone call data for Tanzania, shows that combining the distance variable with a dummy variable that discriminates between dyads that do and do not include the capital city, Dar Es Salaam, leads to significant improvements in the explanatory power of the gravity model, with no need for mass variables any longer. This result suggests that the use of population size as a mass variable may be inadequate for developing countries, because it does not discriminate well in terms of socio-cultural patterns, political power, and the type of economic activities in an urban system in early stages of development. Rossera (1990) and Rietveld and Janssen (1990), using intra-Switzerland and international Dutch-originating call data, introduce the concept of barriers into a gravity-like models via dummy variables (e.g., linguistic differences). Finally, Fisher and Gopal (1994) use artificial neural networks to estimate a model of Austrian interregional telephone flows.

Economic studies emphasize price and income effects. Larsen and McCleary (1970) regress residential and business interstate toll calls on income, price, and the volume of interstate mail. Deschamps (1974) regresses intercity calls on the numbers of subscribers in both cities, the income at the origin city, the toll rate, and dummy variables representing distance ranges. The distance coefficients are all negative and increase with distance. Pacey (1983) estimates a model similar to Deschamps' (1974), but is not able to separate distance and price effects. Both studies obtain price elasticities around -0.24. De Fontenay and Lee (1983) analyze residential calls between British Columbia and Alberta. Second-order models are estimated for the various mileage bands by regressing call minutes on price and income, with price elasticities ranging from -1.12 to -1.65. Guldmann (1992), using regional toll calls, estimates separate residential and business models, for both messages and minutes, with the effects of prices and distance successfully separated, and with price elasticities equal to -0.31 and -0.54 for residential and business calls, and to -1.43 and -1.79 for residential and business minutes. The distance elasticities are slightly below -1.0 for calls and around -0.6 for minutes. In addition, time-of-day flow sharing models are estimated, leading to cross-price elasticities.

Another, more recent, stream of point-to-point studies has been initiated by the seminal paper by Larson et al. (1990), who extend the basic theory of telephone demand presented in Taylor (1980), by using reverse traffic (from j to i) as a determinant of the traffic from i to j. Their theoretical framework is briefly summarized. Two economic agents, a and b, have utility functions of the form U(X,I), where X is the usual composite good, and I the "information" good, which is produced through a production function of the form $I = f(Q_{ab},Q_{ba})$. Q_{ab} and Q_{ba} are the directional telephone flows between a and b. Each agent is assumed to maximize its utility subject to its income constraint and its information production constraint, leading to a Nash equilibrium for the telephone flows, with: $Q_{ab} = W(p,q,M_a,Q_{ba})$ and $Q_{ba} = Z(p,q,M_b,Q_{ab})$, where M is the income, p the price of the composite good, and q the price of telephone. Larson et al. analyze high-density intra-LATA toll routes consisting each of a large metropolitan area (A) and a relatively small suburb or town (B). Traffic flow from A to B is taken as a function of telephone rates, income, market size expressed as the product of the populations at A and B, and traffic from B to A. The call back (reverse traffic) coefficient is estimated at 0.75 for the A-to-B equation, and at 0.67 for the reverse one. This idea is implemented by Appelbe et al. (1988) in their analysis of Canadian interprovincial and Canada-U.S. flows. Using long-distance direct-dial MTS (Measured Toll Service) data from the six Telecom Canada member companies, they regroup inter-provincial and Canada-U.S. routes by mileage band, and combine these bands with two rate periods (full and discount). Then, for each combination, they estimate point-to-point models, with, as dependent variables, the deflated revenues for intra-Canada flows, and billed minutes for Canada-U.S. flows. The independent variables include price, income, size of the originating market (the numbers of residential and business access lines), and the reverse traffic. The call back coefficients range from 0.38 to 0.72. Similar models are estimated by Appelbe and Dineen (1993) for Canada-Overseas MTS minutes, and by Guldmann (1998), who analyzes intersectoral regional toll flows, with the economy disaggregated into four sectors (Manufacturing, Trade, Services, and Households). In all these studies, simultaneous equation estimation procedures are used. Martins-Filho and Mayo (1993), departing from this estimation approach, account for the reverse traffic effect by estimating the correlation of the flows of transposed exchanges. They use data for 4 major Tennessee metropolitan areas to regress point-to-point calls on (1) a price variable measuring the cost of a three-minute duration call, (2) a market size variable equal to the product of the numbers of subscribers at the two points, and (3) dummy variables representing different distance ranges. The call back effect is estimated around 0.40.

III. CONCEPTUAL FRAMEWORK

The modeling approach builds upon the point-to-point models reviewed in Section II, and extends them by accounting for the effect of the spatial structure on telecommunication flows. Let F_{ij} be a measure of the flow from location i to location j, D_{ij} the distance from i to j, P_{ij} the telephone price per unit flow from i to j, and XO_i and XD_j variables characterizing the flow-originating market at i and the flow-receiving market at j, respectively. The Larson-type model can be summarized as follows:

$$F_{ij} = f(F_{ji}, D_{ij}, P_{ij}, XO_i, XD_j) \quad (1)$$

The endogenous return flow F_{ji} is, of course, defined by:

$$F_{ji} = f(F_{ij}, D_{ij}, P_{ji}, XO_j, XD_i) \quad (2)$$

Combining Eqs. (1) and (2) produces a reduced-form relationship, whereby F_{ij} is a function of the exogenous variables only, with:

$$F_{ij} = g(D_{ij}, P_{ij}, P_{ji}, XO_i, XO_j, XD_i, XD_j) \quad (3)$$

Except for Leinbach (1973) and Hirst (1975), none of the previous studies has accounted for the effects of the spatial structure on the telecommunication interactions between locations. The spatial interaction literature suggests, both theoretically and empirically, that improved models are to be obtained by accounting for such effects, particularly in eliminating the estimation bias of the distance parameter. One approach, proposed by Fotheringham (1983a, 1983b), is to introduce into the model a competing destination (CD) factor, that measures the accessibility of the destination j to all (or a subset of) the other destinations. If the interaction decreases with this factor, competition is deemed to exist among the destinations, and the closer a specific destination j is to other destinations, the smaller the interaction terminating at j. In the opposite case, agglomeration effects are deemed to take place. CD factors have been used, among others, by Ishikawa (1987) in modeling migration and university enrollments in Japan, Guy (1987) in modeling shopping travel, Fik and Mulligan (1990) in modeling airline traffic, and Fik et al. (1992) in modeling interstate labor migration. Both competition and agglomeration effects were uncovered in these different studies. Another approach involves the use of an intervening opportunities (IO) factor, based on the ideas developed by Stouffer (1940, 1960), who argued that the observed attenuating effects of distance represent the absorbing effects of those opportunities located between the origin and the ex post destination. IO factors have been used, among others, by Barber and Milne (1988) in modeling internal migration in Kenya, by Fik and Mulligan (1990) and Fik et al. (1992), together with CD factors, and by Conçalves and Ulysséa-Neto (1993) in modeling public transportation flows.

While reviewing the above studies, one can oberve a significant variability in the definition of the geographical space over which the CD/IO factors are computed. For instance, Stouffer (1940, 1960) alternatively defines that space as (1) a circle centered at the origin i with radius D_{ij} , and (2) a circle passing through i and j , and with diameter D_{ij}. Barber and Milne (1988), in contrast, consider all destinations, except i and j. Likewise, the CD factor may be computed over the whole space, except j (Ishikawa, 1987), or it may be restricted to a circle centered at j (e.g., all points k so that $D_{kj} \leq D_{ij}$). The selection of the CD/IO destinations may be further restricted by hierarchical considerations (Fik and Mulligan, 1990). An additional factor of variability is the role of distance in computing the CD/IO factors. In general, destination masses are divided by a power of the distance between the CD/IO destination and either i (IO) or j (CD). This power is often exogenously specified, but may also be iteratively estimated (Fotheringham, 1983a), or may be set equal to zero (Stouffer, 1940, 1960; Conçalves and Ulysséa-Neto, 1993).

In this study, we consider separately one CD and three IO factors, as illustrated in Figures 1-4. Let XD_k be the mass variable characterizing the competing or intervening destination k. The CD factor, CDS_{ij}, is defined over a circle centered at j, with radius DL (Figure 1), with:

$$CDS_{ij} = \Sigma_k XD_k / D_{kj}^{\lambda} \qquad k \neq (i, j),\ D_{kj} \leq DL,\ \lambda \geq 0 \tag{4}$$

All the IO factors are defined by formulas similar to Eq. (4), using distance D_{ki} instead of D_{kj}. The first IO factor, OCL_{ij}, is defined over a circle centered at i (Figure 2). The second IO factor, OCS_{ij}, is defined over a circular sector centered at i, with symmetry axis i-j, angle $2\alpha_o$, and radius DL (Figure 3). The third IO factor, OCR_{ij}, is defined over a rectangular corridor with length D_{ij} and width 2*DY (Figure 4). Because the literature does not provide strong guidance as to the relevant space over which to compute the CD/IO factors, we conduct extensive sensitivity analyses over the geometrical parameters DL, DY, and α_o, while also also varying the distance exponent λ, in order to identify the structure that best improves the overall explanatory power of the interaction model. The basic model (1) is then reformulated as

$$F_{ij} = f\ (\ F_{ij}\ ,\ D_{ij}\ ,\ P_{ij}\ ,\ XO_i\ ,\ XD_j\ ,\ A_{ij}\ )\ , \tag{5}$$

where $A_{ij} = CDS_{ij}$, OCL_{ij}, OCS_{ij}, or OCR_{ij}.

IV. EMPIRICAL ANALYSES

4.1 Data

The data pertain to a 5 percent random sample of all the toll calls that were made within a certain LATA (Local Access and Transport Area) somewhere in the United States during the month of February 1990. Because of the proprietary nature of the information, the name of the Local Exchange Company (LEC) that provided the data may not be revealed, and any parameter that might be used to identify it is given on an interval basis only. The LATA has a total area of [25,000-35,000] square kilometers, a 1990 population of [0.8-1.5] million, and [250-350] county subdivisions (city, town, village) spread over [10-15] counties. The LATA is subdivided into [100-200] wire centers (WCs), each with a central office building housing one or more switches, to which all local loops converge. All calls are intra-LATA exclusively, i.e., originate and terminate within the LATA.

The sample is made of [500,000-700,000] calls. Each message is characterized by a large number of variables, including the message date, starting time (hour/minute), duration, and charge, and the coordinates of the two wire centers where the message originates and terminates. Toll messages are classified according to their service categories: (1) MTS (Message Toll Service) messages originating at private residential and business stations; (2) MTS-Coin messages originating at coin stations; (3) Out-WATS (Wide-Area Toll Service) messages originating at a WATS number; and (4) In-WATS messages (exclusively 800 calls). Only non-coin MTS and Out-WATS calls were retained, because (a) In-WATS 800 calls have no spatial specificity, i.e., the location of the 800 number is not available, and (b) the usage pattern of coin stations is very different from that of private stations, particularly regarding return calls, which are an important feature of this analysis. In-WATS 800 calls represent 8% of all calls, and coin-MTS calls 3%. Their exclusion from the data base is unlikely to bias the results because these calls represent different types of interactions, with little substitutability for regular toll calling. Only MTS calls have their charge included in the data base. The pricing of Out-WATS service involves (1) a fixed monthly access line charge, and (2) a monthly usage charge related to the monthly hourly usage through a declining block rate structure, irrespective of the timing of a call or the location of its destination. Given the rate structure in effect in February 1990, the total monthly usage and the resulting total monthly charge have been estimated for each Out-WATS number in the sample The resulting average charge (¢/second) has then been used to estimate an equivalent charge for each individual call, based on its duration.

The basic unit of observation is the link between location (wire center) i and location j ($i \neq j$). Individual call data have been aggregated for each link, which is characterized by the following variables:

MS_{ij} = number of conversation seconds from i to j,

MC_{ij} = total charge (¢) for all the conversation seconds from i to j.

An average price is then derived by dividing total charge by total call duration:

$P_{ij} = MC_{ij}/MS_{ij}$ (¢/second)

Because of the simultaneous equation estimation approach used in this study, it was necessary to organize the data base by pairing each link (i,j) with the reverse link (j,i). In a few cases, there was no flow on the reverse link, i.e., $MS_{ji} = 0$ while $MS_{ij} > 0$. These cases, which represent about 1.77% of the conversation seconds, were discarded because it was impossible to indirectly estimate the price variable for the link (j,i). As the final sample includes many links with low traffic, such discarding should not prevent accounting for the effects of low flows on the estimation of the parameters. After pairing each link with its reverse one, the final data base includes 5,308 observations (i.e., 10,616 uni-directional links). The calling distance varies between 3.1 and 162.1 miles, with an average of 46.2. The average charge is 31.8 ¢/second for link (i,j) and 30.9 for link (j,i). Each of the 5,308 observations in the data base includes the following variables: (1) the numbers of conversation seconds: MS_{ij}, MS_{ji} ; (2) the average prices

(¢/sec.): P_{ij}, P_{ji} ; (3) the distance: D_{ij} ($\equiv D_{ji}$). To these variables are added variables measuring the sizes of the wire centers (WCs) i and j. The size of WC i is characterized by the total telephone flows originating and terminating at i, with:

- MSO_i: total number of conversation seconds originating at i,
- MSD_i: total number of conversation seconds terminating at i.

These corresponding variables for location j are also included in each observation.

4.2 Model Specification

Let the number of conversation seconds, MS_{ij}, represent the telecommunication flow variable F_{ij}, and the total originating and terminating flows, MSOi and MSDj, the variables XO_i and XD_j . Equation (5) is then reformulated as

$$MS_{ij} = f\,(MS_{ji} , D_{ij} , P_{ij} , MSO_i , MSD_j , A_{ij}) , \tag{6}$$

where the CD/IO factor A_{ij} is computed with Eq. (4) while replacing the variable XD_k by the variable MSD_k. We assume a multiplicative functional form, with:

$$MS_{ij} = K_o\, MS_{ji}^{\ \alpha}\, D_{ij}^{\ \beta}\, P_{ij}^{\ \gamma}\, MSO_i^{\ \delta}\, MSD_j^{\ \varepsilon}\, A_{ij}^{\ \theta I ij} , \tag{7}$$

where K_o is a multiplicative constant, and I_{ij} is a dummy variable, with I_{ij}=1 if $A_{ij} > 0$, and I_{ij}=0 if A_{ij} =0. The use of this dummy variable is made necessary to guarantee that the last factor in Eq. (7) is equal to one when A_{ij} =0, which happens when the CD/IO space is small and does not contain CD/IO destinations. Because of the reverse flows, a simultaneous equation estimation approach is necessary. The set of log-linear structural equations is then:

$$\ell nMS_{ij} = \ell nK_0 + \alpha \ell nMS_{ji} + \beta \ell nD_{ij} + \gamma \ell nP_{ij} + \delta \ell nMSO_i + \varepsilon \ell nMSD_j + \theta I_{ij}\ \ell nA_{ij} \tag{8}$$

$$\ell nMS_{ji} = \ell nK_0 + \alpha \ell nMS_{ij} + \beta \ell nD_{ij} + \gamma \ell nP_{ji} + \delta \ell nMSO_j + \varepsilon \ell nMSD_i + \theta I_{ji}\ \ell nA_{ji} \tag{9}$$

4.3 Results

The system of structural equations (8)-(9) has been estimated using the iterative three-stage least squares procedure, which corrects for both heteroskedasticity and error correlation across equations, and provides consistent and asymptotically efficient coefficient estimates. To be used as a comparative benchmark, the model has first been estimated without the CD/IO factor A_{ij} , with:

$$\ln MS_{ij} = \underset{(9.72)}{-2.781} + \underset{(12.11)}{0.135}\ln MS_{ji} - \underset{(23.48)}{0.640}\ln D_{ij} - \underset{(80.07)}{1.759}\ln P_{ij} + \underset{(51.01)}{0.594}\ln MSO_i + \underset{(48.65)}{0.627}\ln MSD_j \quad (10)$$

The t-statistics are in parentheses below each coefficient. The system-weighted R^2 is equal to 0.642. The cross-equations restrictions (Eqs. 8 and 9 must have the same coefficients) are all accepted at the 5% level of significance. Also, a comparison of Eq. (10) with that obtained with the two-stage least squares procedure shows that both equations are very similar, because there is very little error correlation across equations. As could be expected, the effect of the telephone price is negative and highly significant, in the elastic range. The effect of distance is also negative and highly significant. The coefficients for the origin and destination market size variables are all positive, as expected, and highly significant. The call-back coefficient (i.e., the reverse flow coefficient) provides important information about the nature of the information function associated with the interlocational transactions. As discussed in Larson et al. (1990), when this coefficient is positive, the two flows are complementary, that is, they are both necessary in contributing to the information needed by both parties. When it is negative, a substitution effect takes place: there is a given, finite amount of necessary information, which may be contributed by either party. Finally, if the coefficient is zero, the information-gathering process is initiated and completed by one party only. In the above model, the positive coefficient points to complementarity. Its value (0.135) is on the low side when compared to the call-back coefficients obtained by Larson et al. (1990), Appelbe et al. (1988), and Martins-Filho and Mayo (1993), which are in the [0.38-0.75] range.

The benchmark model (Eq. 10) has been extended by introducing separately each of the four CD/IO factors discussed in Section III. In all cases, the coefficient of this factor is negative and highly significant, clearly pointing to competitive effects. Consider first the case of the CD factor, CDS_{ij}. Three values of the distance exponent λ (0, 1, 2) are combined with three radii of the circle containing the competing destinations. The circle radius is specific to each link i-j, with $DL_{ij} = h*D_{ij}$ (the radius DL_{ij} is proportional to the link length D_{ij}). The first radius, with h=1000, implies a circle enclosing the whole LATA (the minimum D_{ij} is equal to 3.1 miles), and therefore a CD factor that measures the accessibility of j to all other destinations in the LATA, except i. The second radius, with h=1.0, implies a circle passing through the origin i ($D_{kj} \leq D_{ij}$). The third radius, with h=0.5, implies a circle passing through the mid-point of link i-j. The estimation results are presented in Table 1. If the system-weighted R^2 is taken as the selection criterion, the best model corresponds to the case (h=1000, λ=1), with $R^2 = 0.715$, or a gain of 7.3% over the benchmark model (Eq. 10). The results suggest that the smaller the space (circle) over which the CD factor is computed, the smaller the R^2. The poorer results obtained with (h=1000, λ=0) suggest that destination masses must indeed be weighted by an inverse function of distance, and the value of λ=1 seems to generally provide the best results, if only marginally so. The results obtained when using the IO factor OCL_{ij}, and presented in Table 2, are overall very similar to those obtained with CDS_{ij} (and identical, as expected, when h=1000 and λ=0). The best model again corresponds to the case (h=1000, λ=1), with R^2=0.717, or a gain of 7.5%. The results obtained when using the IO factor OCS_{ij} are presented in Table 3. The estimates display little variations over the different values of λ, and only the results for λ=1 are reported. The smaller the radius DL_{ij} and the smaller the sector angle $2\alpha_o$, the smaller the R^2. The best result is obtained when $2\alpha_o = 180^o$ and h=1000, with R^2=0.698, or a gain of 5.6% Finally, the results obtained when using the IO factor OCR_{ij} , and presented in Table 4, are consistent with all previous results, indicating that the wider the corridor, the higher the R^2, and the best model is obtained when λ=2 and the corridor is a square ($2*DY=D_{ij}$), with R^2=0.661, or a gain of 1.9% over the benchmark case.

Several conclusions emerge from the previous analysis. First, the spatial structure has clearly an effect on telecommunication flow patterns, confirming the earlier results of Leinbach (1973) and Hirst (1975), and this effect is of a competitive type. The maximum explanatory gain of 7.5% is consistent with similar gains reported in the literature. Second, the more inclusive the space over which the CD/IO factors are computed, the higher the explanatory gain. Accounting for all destinations (except i and j) brings about the best results. In other words, all destinations compete and the spatial structure effect is regionwide. Restricting the selected destinations to directional corridors or circular sectors, while a priori logical, leads to an explanatory power loss. Third, destination masses should be inversely weighted by a function increasing with distance. The limited sensitivity analyses conducted over the distance exponent λ do not permit firm conclusions as to the optimal exponent value, although λ=1 seems to provide generally good results.

Fotheringham (1983) argues that, in the absence of a CD factor, the effects of the spatial structure are reflected in the distance exponent, which is then necessarily biased. It may therefore be interesting to assess the changes in the coefficients of the benchmark model (Eq. 10) when CD/IO factors are included. First, notice that the coefficients of the price (P_{ij}) and mass

(MSO_i , MSD_j) variables display only minor variations in most cases reported in Tables 1-4. When opportunities sectors and corridors are considered (Tables 3-4), the reverse flow coefficients are generally of the same magnitude as in the benchmark model, and the distance coefficients vary within the range [-0.35; -0.50], smaller than in the benchmark case (-0.64), thus in support of Fotheringham’s argument. Similar results are also obtained for the smaller circles (h=1.0, h=0.5) in Tables 1-2. However, in the case of the overall “best” model in Table 2 (λ=1, h=1000), the introduction of the IO factor has not significantly changed the distance coefficient (-0.623 vs. -0.640), has slightly reduced the price elasticity (-1.652 vs. -1.759), but has significantly increased the call-back coefficient (0.276 vs. 0.135). This would suggest that, at least in the case of telecommunication interactions, the bias created by not accounting for the spatial structure may be reflected through variables other than distance.

Finally, to fully account for the effects of the exogenous variables (distance, prices, market sizes, CD/IO factors) on the endogenous variable MS_{ij} , it is necessary to derive the reduced-form equation from the structural equations. For illustration purposes, consider the case of the best model in Table 2 (h=1000, λ=1). Combining the equations for MS_{ij} and MS_{ji} yields the reduced-form equation:

$$\ln MS_{ij} = 14.504 - 0.861\ln D_{ij} - 1.789\ln P_{ij} - 0.494\ln P_{ji} + 0.694\ln MSO_i + 0.162\ln MSD_i$$
$$+ 0.587\ln MSD_j + 0.192\ln MSO_j - 0.873\ln OCL_{ij} - 0.241\ln OCL_{ji} \qquad (11)$$

The coefficients of Eq. (11) represent the true elasticities of the dependent variable MS_{ij} with respect to the independent variables. The bi-directional price elasticity, which measures the percent change in flow if both the direct (P_{ij}) and reverse (P_{ji}) prices increase by one percent, is equal to -2.283 (=-1.789-0.494). Similarly, if the size of the origin market i increases by one percent, it is reasonable to assume that this increase will equally affect both variables MSO_i and MSD_i , with a total elasticity of 0.856. The corresponding total elasticity for the destination market j is 0.779. Finally, the total elasticity of the IO factors is equal to -1.114.

V. CONCLUSIONS

Inter-city telecommunication flows have been analyzed by estimating spatial interaction models that account for the effects of the spatial structure, and various formulations of competing destinations and intervening opportunities factors have been considered through extensive sensitivity analyses. The results indicate that the spatial structure effects are of a competitive nature and regionwide. Restricting the competition space to the neighborhoods of the origin or destination cities leads to inferior model performance. The results also suggest that these competitive effects decrease with the distance from the competing destination.

Further research should involve the interfacing of the telephone flow data with socio-economic data (e.g., population, income, employment, sales), as derived from population and economic censuses, in order to better characterize the call originating and terminating markets. Such data would allow for the computation and testing of more diversified factors reflecting the effects of the spatial structure. Further disaggregation of the modeling approach both temporally and by the type of economic activity involved in the telecommunication interaction might also allow for a more precise assessment of the spatial structure effects. Research is underway in these areas and will be reported in the near future.

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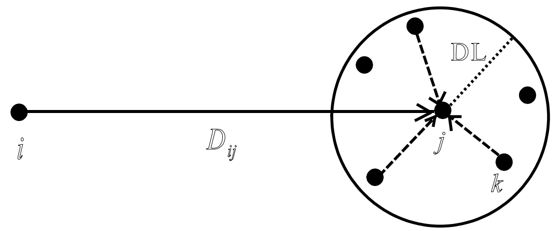

Figure 1 Competing Destination Circle for the Flow F_{ij}

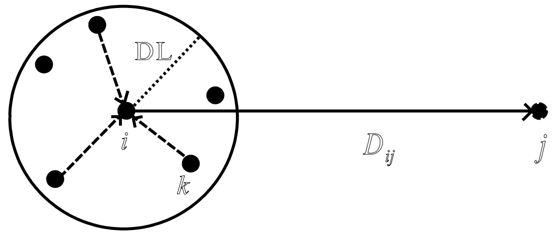

Figure 2 Intervening Opportunities Circle for the Flow F_{ij}

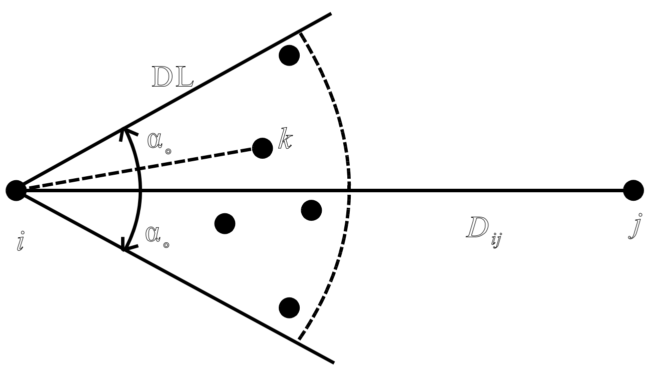

Figure 3 Intervening Opportunities Sector for the Flow F_{ij}

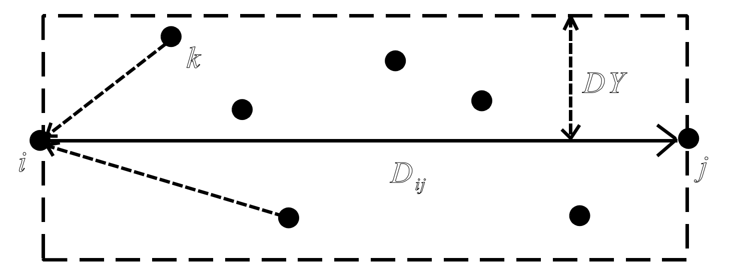

Figure 4 Intervening Opportunities Corridor for the Flow F_{ij}

TABLE 1 Regression Models for Conversation Seconds (MS_{ij}) - Case of Competing Destinations Circles

Variable	$h=1000^1$			$h=1.0$			$h=0.5$		
	$\lambda=0^2$	$\lambda=1$	$\lambda=2$	$\lambda=0$	$\lambda=1$	$\lambda=2$	$\lambda=0$	$\lambda=1$	$\lambda=2$
Intercept	344.230 (22.23)[3]	10.378 (22.05)	1.253 (4.88)	-1.598 (6.17)	-1.592 (6.18)	-1.732 (6.76)	-2.987 (10.96)	-2.932 (10.80)	-2.893 (10.70)
$\boldsymbol{lnMS_{ji}}$	0.099 (8.77)	0.257 (26.32)	0.243 (24.61)	0.177 (16.90)	0.180 (17.22)	0.187 (18.00)	0.161 (15.01)	0.162 (15.13)	0.164 (15.31)
$\boldsymbol{lnD_{ij}}$	-0.701 (25.61)	-0.638 (27.73)	-0.624 (26.68)	-0.281 (10.78)	-0.423 (17.51)	-0.530 (22.08)	-0.410 (15.37)	-0.448 (17.30)	-0.482 (18.94)
$\boldsymbol{lnP_{ij}}$	-1.768 (82.13)	-1.691 (81.72)	-1.710 (82.11)	-1.746 (82.43)	-1.748 (82.62)	-1.748 (82.55)	-1.756 (81.78)	-1.756 (81.83)	-1.755 (81.86)
$\boldsymbol{lnMSO_i}$	0.450 (36.21)	0.534 (50.85)	0.544 (51.08)	0.606 (53.04)	0.596 (52.82)	0.582 (52.19)	0.590 (51.89)	0.589 (51.90)	0.587 (51.88)
$\boldsymbol{lnMSD_j}$	0.473 (34.83)	0.689 (48.76)	0.683 (48.70)	0.670 (50.34)	0.682 (50.22)	0.678 (49.62)	0.643 (49.53)	0.646 (49.57)	0.648 (49.59)
$\boldsymbol{lnCDS_{ij}}$	-15.876 (22.38)	-0.815 (28.15)	-0.366 (25.48)	-0.191 (21.45)	-0.197 (21.61)	-0.182 (20.63)	-0.060 (16.32)	-0.066 (16.67)	-0.073 (16.87)
System-Weighted R^2	0.660	0.715	0.703	0.677	0.678	0.677	0.663	0.664	0.664

[1] Circle Multiplier ($DL=h_*D$) [2] Distance exponent in competing destination factor CDS_{ij}
[3] The t- statistics are in parentheses

TABLE 2 Regression Models for Conversation Seconds (MS_{ij}) - Case of Intervening Opportunities Circles

Variable	$h=1000$[1]			$h=1.0$			$h=0.5$		
	$\lambda=0$[2]	$\lambda=1$	$\lambda=2$	$\lambda=0$	$\lambda=1$	$\lambda=2$	$\lambda=0$	$\lambda=1$	$\lambda=2$
Intercept	344.230 (22.23)[3]	10.498 (22.55)	1.387 (5.38)	-1.482 (5.72)	-1.434 (5.58)	-1.576 (6.16)	-2.904 (10.72)	-2.843 (10.54)	-2.801 (10.41)
$lnMS_{ji}$	0.099 (8.77)	0.276 (28.91)	0.254 (26.00)	0.177 (17.04)	0.183 (17.74)	0.191 (18.52)	0.165 (15.51)	0.167 (15.66)	0.168 (15.79)
lnD_{ij}	-0.701 (25.61)	-0.623 (27.82)	-0.614 (26.58)	-0.261 (9.98)	-0.411 (17.03)	-0.524 (21.95)	-0.409 (15.34)	-0.445 (17.22)	-0.479 (18.86)
lnP_i	-1.768 (82.13)	-1.652 (80.19)	-1.690 (81.30)	-1.747 (82.77)	-1.745 (82.75)	-1.745 (82.66)	-1.752 (81.62)	-1.752 (81.67)	-1.752 (81.74)
$lnMSO_i$	0.450 (36.21)	0.641 (52.77)	0.642 (52.22)	0.638 (54.04)	0.647 (54.00)	0.644 (53.31)	0.605 (52.17)	0.607 (52.24)	0.609 (52.24)
$lnMSD_j$	0.473 (34.83)	0.542 (46.18)	0.560 (46.89)	0.642 (50.64)	0.628 (50.23)	0.611 (49.36)	0.618 (49.00)	0.616 (48.99)	0.615 (48.93)
$lnOCL_{ij}$	-15.826 (22.38)	-0.806 (28.71)	-0.361 (25.46)	-0.204 (23.06)	-0.209 (23.19)	-0.192 (21.92)	-0.059 (16.04)	-0.065 (16.43)	-0.071 (16.56)
System-Weighted R^2	0.660	0.717	0.704	0.678	0.680	0.679	0.663	0.664	0.664

[1] Circle Multiplier (DL=h*D) [2] Distance exponent in intervening opportunities factor OCL_{ij}
[3] The t- statistics are in parentheses

TABLE 3 Regression Models for Conversation Seconds (MS_{ij}) - Case of Intervening Opportunities Sectors

Variable	$h = 1000$[1]			$h = 1.0$			$h = 0.5$		
	$\alpha_0 = 90°$[2]	$\alpha_0 = 45°$	$\alpha_0 = 22.5°$	$\alpha_0 = 90°$	$\alpha_0 = 45°$	$\alpha_0 = 22.5°$	$\alpha_0 = 90°$	$\alpha_0 = 45°$	$\alpha_0 = 22.5°$
Intercept	3.416 (11.10)[3]	-0.367 (1.34)	-1.895 (6.99)	-2.478 (9.22)	-2.980 (10.78)	-3.453 (12.13)	-3.203 (11.72)	-3.409 (12.24)	-3.313 (11.62)
$\ln MS_{ji}$	0.226 (22.70)	0.202 (19.51)	0.175 (16.40)	0.154 (14.48)	0.148 (13.67)	0.142 (12.99)	0.168 (15.77)	0.163 (15.28)	0.157 (14.48)
$\ln D_{ij}$	-0.507 (22.69)	-0.486 (20.33)	-0.525 (20.64)	-0.426 (16.48)	-0.458 (17.01)	-0.454 (16.50)	-0.427 (16.33)	-0.419 (15.56)	-0.470 (16.82)
$\ln P_{ij}$	-1.718 (82.44)	-1.751 (82.41)	-1.762 (81.91)	-1.757 (82.33)	-1.756 (81.43)	-1.752 (80.87)	-1.749 (81.49)	-1.749 (81.29)	-1.753 (80.79)
$\ln MSO_i$	0.614 (53.30)	0.583 (51.55)	0.583 (51.25)	0.641 (53.74)	0.617 (52.58)	0.613 (52.23)	0.603 (52.13)	0.600 (52.06)	0.596 (51.40)
$\ln MSD_j$	0.636 (49.65)	0.635 (48.49)	0.629 (48.55)	0.656 (50.86)	0.648 (49.99)	0.649 (49.70)	0.622 (49.11)	0.624 (49.16)	0.623 (48.73)
$\ln OCS_{ij}$	-0.468 (25.81)	-0.215 (17.46)	-0.097 (12.79)	-0.150 (20.33)	-0.083 (15.78)	-0.053 (14.67)	-0.053 (16.17)	-0.041 (15.31)	-0.025 (11.02)
System-Weighted R^2	0.698	0.674	0.660	0.667	0.658	0.656	0.664	0.661	0.654

[1] Circle Multiplier ($DL=h_*D$) [2] Half-sector angle in intervening opportunities factor OCS_{ij}
[3] The t- statistics are in parentheses

TABLE 4 Regression Models for Conversation Seconds (MS_{ij}) - Case of Intervening Opportunities Corridors

Variable	$\ell = 0.5$[1]			$\ell = 0.3$			$\ell = 0.1$		
	$\lambda = 0$[2]	$\lambda = 1$	$\lambda = 2$	$\lambda = 0$	$\lambda = 1$	$\lambda = 2$	$\lambda = 0$	$\lambda = 1$	$\lambda = 2$
Intercept	-3.112 (11.10)[3]	-2.943 (10.67)	-2.892 (10.53)	-3.512 (12.25)	-3.384 (11.97)	-3.334 (11.85)	-3.746 (12.65)	-3.681 (12.54)	-3.655 (12.48)
$\boldsymbol{lnMS_{ji}}$	0.136 (12.42)	0.149 (13.81)	0.151 (14.06)	0.133 (12.09)	0.143 (13.09)	0.144 (13.24)	0.131 (11.79)	0.136 (12.35)	0.136 (12.31)
$\boldsymbol{lnD_{ij}}$	-0.366 (12.51)	-0.423 (15.64)	-0.497 (19.11)	-0.396 (13.55)	-0.429 (15.49)	-0.475 (17.75)	-0.417 (13.64)	-0.428 (14.46)	-0.450 (15.53)
$\boldsymbol{lnP_{ij}}$	-1.755 (81.24)	-1.756 (81.64)	-1.754 (81.59)	-1.750 (80.69)	-1.751 (80.98)	-1.749 (80.96)	-1.749 (80.15)	-1.750 (80.35)	-1.750 (80.33)
$\boldsymbol{lnMSO_i}$	0.628 (53.12)	0.628 (52.98)	0.633 (52.88)	0.623 (52.74)	0.623 (52.65)	0.629 (52.67)	0.615 (52.14)	0.615 (52.07)	0.619 (52.08)
$\boldsymbol{lnMSD_j}$	0.665 (50.68)	0.650 (50.29)	0.641 (50.04)	0.659 (50.30)	0.648 (50.04)	0.643 (49.94)	0.650 (49.74)	0.644 (49.59)	0.641 (49.56)
$\boldsymbol{lnOCR_{ij}}$	-0.096 (17.14)	-0.104 (17.55)	-0.106 (17.31)	-0.063 (15.84)	-0.070 (16.19)	-0.075 (16.29)	-0.035 (12.93)	-0.040 (13.14)	-0.044 (13.04)
System-Weighted R^2	0.657	0.660	0.661	0.654	0.657	0.658	0.650	0.651	0.651

[1] Corridor Width Multiplier ($DY=\ell_* D$) [2] Distance exponent in intervening opportunities factor OCR_{ij}
[3] The t- statistics are in parentheses