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Intersectoral point-to-point telecommunication flows: theoretical framework and empirical results

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Abstract

Based on a theoretical framework that derives information flows associated to economic and social transactions, intersectoral, point-to-point telecommunication flow functions are specified and estimated, using a very large data base on intra-LATA toll calls and a simultaneous equation estimation procedure that accounts for the endogeneity of reverse call flows. The effects of prices, distances, and market sizes vary significantly across intersectoral interactions, and so does the impact of reverse calls, pointing to different cases of information complementarity and substitutability. Flows always decrease with distance, pointing to complementarity between transportation and telecommunications. The demand for messages is always price-inelastic, while the demand for conversation minutes is always elastic. Overall, intra-residential calling appears to be most sensitive to telecommunication prices. Several areas for further research are outlined. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

An extensive literature discussing the spatial impacts of telecommunications, a comprehensive synthesis of which can be found in Graham and Marvin (1996),

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has emerged in recent years. The issues include the decentralization of manufacturing, the emergence of network firms, the relocation of office activities, the agglomeration of financial services in large metropolitan areas, the revival of rural areas, and telecommunication/transportation interactions, all arising from the potential of the technology to overcome time and distance constraints. One intriguing aspect of this literature is its primarily conceptual nature, backed with very little systematic empirical research. This situation is not surprising in view of the difficulties in securing proprietary data from telephone companies, and is likely to worsen with the accelerating trend towards complete deregulation and competition in all telecommunication markets. As Staple and Mullins (1989) put it, telecommunication circuits are the electronic highways of the modern economy, but very little is known on the volume and character of the traffic they carry.

The purpose of this paper is to contribute to the above debates and to a better understanding of the spatial structure of telecommunication demand through an econometric analysis of regional point-to-point telecommunication flows, making use of a very rich data base on regional telephone calls. The empirical analyses rely on a theoretical framework that extends the basic microeconomic models of the firm and the consumer by considering information exchanges made possible by telecommunication technologies and required to complete economic and social transactions. A general telecommunication demand function is formulated, that serves as a basis for the specification and estimation of intersectoral point-to-point telecommunication flow functions. The approach implies that calls made between different parties (or clusters of like parties) are different products, with different demand parameters (e.g. elasticities). This disaggregation makes it easier to account, for instance, for the diversity of telecommunication needs across businesses, which vary from sales and marketing to purchasing to intra-firm communications. The analysis identifies major intersectoral interactions and provides insights into the role of information in intersectoral economic exchanges, and in particular whether information flows are complementary or substitutable. The results show that the roles of information, distance as proxy for transportation cost, telecommunication prices, and the sizes of the local markets, all vary from one economic interaction to another.

The remainder of the paper is organized as follows. Section 2 consists in a review of the relevant literature. The theoretical framework is presented in Section 3. The data sources, functional specifications, and empirical results are reviewed and discussed in Section 4. Conclusions and areas for further research are outlined in Section 5.

2. Literature review

This review is restricted to models of point-to-point telecommunication flows. For extensive reviews of nonspatialized models, see Taylor (1980, 1994). Gravity-

type models have been developed by both geographers and economists, and have been applied to intra-regional, inter-regional, and international flows. Some more recent models have also incorporated reverse flows, based upon an important theoretical contribution by Larson et al. (1990).

Geographical studies emphasize the effects of distance and place size/centrality. The earliest study of intercity telephone flows appears to be by Hammer and Iklé (1957), who regressed the total number of telephone calls, in both directions, between pairs of cities, on airline distance and numbers of subscribers. Using data from Malaysia, Leinbach (1973) regressed the number of intercity messages on distance and city modernization scores derived from a principal component analysis of various socio-economic variables, providing convincing evidence of the influence of the spatial structure on the pattern of flows. Hirst (1975), using call data for Tanzania, combined distance with dummy variables pertaining to the capital and dominant city, suggesting that the population variable may be inadequate to account for political power and other socio-cultural factors in developing countries. More recently, Rossera (1990) and Rietveld and Janssen (1990), using intra-Switzerland and international Dutch-originating call data, introduced the concept of barriers into gravity-like models via dummy variables of linguistic differences. Finally, Fischer and Gopal (1994) used artificial neural networks to estimate a gravity-type model of Austrian interregional telephone flows.

Economic studies emphasize price and income effects. Larsen and McCleary (1970) regressed, separately, the numbers of residential and business interstate toll calls on income, prices, and the volume of interstate mail, which turned out to be the most significant predictor, and obtained price elasticities of -1.01 (residential) and -0.98 (business), but also a negative (and significant) income elasticity. Deschamps (1974) regressed the number of intercity calls on the numbers of subscribers in both cities, the income at the origin city, the toll rate, and dummy variables representing different distance ranges. The distance coefficients were all negative, significant, and increasing with distance. Pacey (1983) estimated a model similar to Deschamps' (Deschamps, 1974), but was not able to separate distance and price effects. Both studies obtained price elasticities around -0.24 . In addition, Pacey developed a model for average intercity call duration, with distance as a positive determinant and a price elasticity of -0.30 , suggesting an elasticity of -0.54 ($0.30 + 0.24$) for minutes demand. De Fontenay and Lee (1983) analyzed residential calls between British Columbia and Alberta, grouping them into seven mileage bands. Second-order models were estimated for each band by regressing the number of minutes on price and income variables. The resulting price elasticities ranged from -1.12 for the 0–20 miles band to -1.65 for the 400–500 band. Guldmann (1992), using intra-LATA (Local Access and Transport Area) toll calls, developed gravity models for both the residential and business sectors, and for both calls and conversation minutes, with the effects of prices and distance successfully separated. The price elasticities were 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 were slightly below -1.0 for calls and around -0.6 for minutes, thus confirming Pacey's observation that call duration increases with distance. Finally, the market (mass) elasticities fell within the range $[0.9-1.0]$. In addition, time-of-day flow sharing models were estimated, leading to detailed cross-price elasticities.

Another, more recent, stream of point-to-point studies was initiated by the seminal paper by Larson et al. (1990), who extended 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. The two extreme cases of information exchange are: (1) perfectly reciprocal calling, where agents return messages in direct proportion to the quantity received, and (2) one-way information exchange, where, once a given amount of information has been transferred, there is no need for further communication. Larson et al. have analyzed high-density intra-LATA toll routes consisting each of a large metropolitan area (A) and a relatively small suburb or town (B), with an average population ratio of 13.6. Residential flows (in minutes) were aggregated over all rate periods. No information was provided as to the geographical location of these routes, nor to their length. Traffic flow from A to B was taken as a function of rates, income, market size expressed as the product of the populations at A and B, and traffic from B to A, with route-specific intercept terms (i.e. dummy variables), but route length was not an explanatory variable. The call back (reverse traffic) coefficient was estimated at 0.75 for the A-to-B equation, and at 0.67 for the reverse one. The resulting bidirectional price elasticities were around -0.75 , and the market size effect turned out to be very small and statistically insignificant. This idea was implemented by Appelbe et al. (1988) in their analysis of Canadian interprovincial and Canada-USA flows (residential and business combined). Using long-distance direct-dial MTS (Measured Toll Service) data from the six Telecom Canada member companies, they regrouped inter-provincial and Canada-USA routes by mileage bands (3 bands for Canada-Canada: 0-750, 750-1600, 1600 + , and two bands for Canada-USA: 0-800, 800 +), and combined these bands with two rate periods (full and discount). Then, for each combination, they estimated point-to-point models, with, as dependent variables, the deflated revenues for intra-Canada flows, and billed minutes for Canada-USA flows. The independent variables included price, income, size of the originating market (the numbers of residential and business access lines), and the reverse traffic. They obtained call

back coefficients ranging from 0.38 to 0.72, unidirectional price elasticities ranging from -0.21 to -0.53 , bidirectional elasticities ranging from -0.36 to -0.75 , and market size elasticities ranging from 0.38 to 1.49. Similar models were estimated by Appelbe and Dineen (1993) for Canada–Overseas MTS minutes, with unidirectional price elasticities ranging from -0.42 to -0.61 . In all these studies, simultaneous equation estimation procedures were used, and the coefficients of the reverse flow always turned out to be highly significant and positive. Martins-Filho and Mayo (1993), departing from this estimation approach, analyzed the welfare implications of extending local calling areas. They used 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. Call data were aggregated over time of day, type of customer (residential plus business), type of service (direct dial, person-to-person, etc.), and day of the week. The reverse traffic effect was accounted for by estimating the correlation of the flows of transposed exchanges, indicating call back effects around 0.40. The distance dummies were negative and significant, the market size elasticity ranged from 0.70 to 0.78, and the price elasticity from -1.18 to -1.54 . Finally, Acton and Vogelsang (1992) used the same framework to study USA–Western Europe telephone flows, but directly estimated the reduced-form equations, without providing structural coefficient estimates.

Except for Larson et al. (1990), all the above studies lack a theoretical framework that would fully explicate the estimated empirical models, in particular how telecommunication flows are linked to economic activities, transactions, and locations, and how telecommunications interact with transportation in enabling the completion of these transactions. Section 3 outlines such a framework.

3. Theoretical framework

Telecommunication systems carry information, in the same way as transportation systems carry goods and people. In both cases, these movements are necessary to complete economic and social transactions. Information exchanges are pervasive throughout the economy, and are associated, to a small or large extent, with all transactions. The demand for such exchanges must therefore be viewed as a derived demand, which can only be understood in relation to the economic and social system in which they take place. In order to achieve a better understanding of the role of telecommunications, we extend the concept of information function proposed by Larson et al. (1990), where information was treated as a stand-alone good similar to all other consumption goods, by linking the information generated by two-way exchanges to basic input and output transactions in a simple model of the firm.

Consider firm A that sells its output Q to firm B. Firm A buys two inputs: materials, M , from firm C, and labor, L , from residential area R. Delivered pricing is assumed to take place, wherein the seller of goods or labor incurs transportation costs. Let P_Q , P_M , and P_L be the competitive market prices of Q , M , and L , and t_{AB} the unit transportation cost of Q from firm A to firm B. Let

$$Q = f(M, L) \quad (1)$$

be the production function of firm A. The standard problem of firm A is to select the values of Q , M , and L that maximize its profit

$$\Pi_A = P_Q Q - P_M M - P_L L - t_{AB} Q \quad (2)$$

subject to the production function constraint (1). To extend this basic model, consider the telecommunication exchanges that may take place between the four parties (A, B, C, R) to complete the above transactions: $\mathbf{F} = (F_{AB}, F_{BA}, F_{AC}, F_{CA}, F_{AR}, F_{RA})$. The completion of the transaction between A and B (sale of Q) requires a certain amount of information, I , that is function of the individual information exchanges F_{AB} and F_{BA} , with: $I_{AB} = g(F_{AB}, F_{BA})$. The relationship between transaction and related information is next expressed by an information constraint:

$$g_Q(Q, I_{AB}) = g_Q(Q, F_{AB}, F_{BA}) = 0 \quad (3)$$

Similar information constraints apply to the M and L transactions, with:

$$g_M(M, F_{AC}, F_{CA}) = 0 \quad (4)$$

$$g_L(L, F_{AR}, F_{RA}) = 0 \quad (5)$$

Let P_{ij} be the unit price of telecommunications from i to j . The expanded profit function of firm A now accounts for the costs of the telecommunication flows initiated by A, with:

$$\Pi_A = P_Q Q - P_M M - P_L L - t_{AB} Q - P_{AB} F_{AB} - P_{AC} F_{AC} - P_{AL} F_{AL} \quad (6)$$

Firm A selects $(Q, M, L, F_{AB}, F_{AC}, F_{AR})$ to maximize (6) subject to the standard production function constraint (1) and the information constraints (3)–(5). The derived input demand functions have, as arguments, (1) the market-determined prices of the output and all inputs, and (2) all the reverse telecommunication flows, the amounts of which are determined by agents B, C, and R. Let \mathbf{P} and \mathbf{RF} be the vectors of prices and reverse flows associated to firm A: $\mathbf{P} = (P_Q, P_M, P_L, t_{AB}, P_{AB}, P_{AC}, P_{AL})$, and $\mathbf{RF} = (F_{BA}, F_{CA}, F_{LA})$. The optimal telecommunication flow from A to B is then expressed as:

$$F_{AB} = h_{AB}(\mathbf{P}, \mathbf{RF}) \quad (7)$$

Similar demand functions would be derived for F_{AC} and F_{AL} , as well as for all the flows initiated by B, C, and R, leading to a Nash equilibrium for all flows. The

above model of firm A could be expanded to include (1) several distinct markets for Q , including other firms as well as final (residential) markets, (2) several sources of inputs (e.g. capital, energy, other materials), and (3) several labor inputs differentiated by skills. Such considerations would simply expand the price and reverse flow vectors, but would not modify the basic structure of (7). Further complications may arise when more than one transaction take place between two parties, e.g. firm A sells some of its output to firm B, but also buys as input some of the output of firm B. Two distinct telecommunication demand functions for flows from A to B would then be associated to these two transactions, but only the sum of these flows would actually be observed by the telecommunication service provider. A similar model could be formulated for a household, which engages in social transactions with other households, sells its labor to firms, and purchases goods and services from firms, while maximizing its utility function subject to budget, commuting, and information constraints, leading to similar information demand functions.

The respective locations of firms and households are prime determinants of the costs/prices of the transportation and telecommunication services they require. It is assumed that the general model (7) is applicable to clusters of similar households and firms located at distinct sites. Define F_{KiLj} as the total flow from sector K at location i , to sector L at location j , with:

$$F_{KiLj} = \sum_{k \in (K, i)} \sum_{l \in (L, j)} F_{kl} \tag{8}$$

where F_{kl} is the telecommunication flow from agent k to agent l . It is reasonable to assume that F_{KiLj} is a function of vectors of reverse flows, \mathbf{RF} , prices, \mathbf{P} , and some measures of the sizes of sectors (K, i) and (L, j) , \mathbf{S} , with:

$$F_{KiLj} = f(\mathbf{RF}, \mathbf{P}, \mathbf{S}) \tag{9}$$

Knowledge of the function f would clarify the role of information in economic and social interactions, and of prices in the demand for this information. The purpose of this paper is to estimate (9).

4. Empirical analysis

4.1. Data

The data pertain to a 5 percent sample of all the toll calls that were made within a certain LATA somewhere in the USA during the month of February 1990. This sample was drawn systematically, with a random starting point, from a billing/accounting data base. Because of the proprietary nature of the information, the name of the LEC (Local Exchange Company) 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. In 1990, [400 000–600 000] people were employed in nonagricultural activities in the LATA, with 21% in manufacturing, 25% in wholesale and retail trade, 35% in private services, and 14% in government. 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. All long-distance inter-LATA calls are handled by carriers such as AT&T and MCI. Note, however, that this organization of the telecommunication industry, which resulted from the break-up of the Bell System in 1984, is again going to change in the near future as a result of the Telecommunications Act of 1996, which allows LECs and long-distance carriers to compete in each other's markets.

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; the coordinates of the two wire centers where the message originates and terminates; and the Standard Industrial Classification (SIC) code of the party (caller, callee, or third party) that pays for the message. A complex data processing was undertaken to assign SIC codes to as many calling and called numbers as possible, and is described in more details in Guldmann (1993). This SIC-code assignment was completed for 73.2% of all the calls in the sample. Toll messages are also 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 noncoin MTS and Out-WATS calls were retained, because (a) In-WATS 800 calls have no spatial specificity, i.e. the location of the paying number is not available, and (b) there is no way of identifying the SIC code of coin station users, i.e. we may know that a given station is classified "Retail Trade" because of its location in a shopping mall, but we do not know who is using it. 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. In addition, a small number of local Out-WATS calls (0.6% of the total sample), which were included in the sample because of the technical way Out-WATS calls are routed, was deleted.

Retaining only the noncoin MTS and nonlocal Out-WATS messages that are fully identified by the SIC codes of the caller and callee, leads to a sample representing 64.5% of the calls and 66.0% of the conversation-seconds that made up the original sample. 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 ($\text{\$/second}$) has then been used to estimate an equivalent charge for each individual call, based on its duration. Before this computation, all individual call counts, their duration, and their charge, were multiplied by 20 to provide estimates for the total population of calls, based on the 5% sample.

While SIC-codes were initially available at the 4-digit level, it was not feasible, because of sample size constraints, to conduct an analysis at this level. Instead, all calls between any pair of originating and terminating wire centers have been aggregated according to four sectors of activity:

- RES: Residential, i.e. private households;
- MAN: Manufacturing, defined in a broad sense, and including Agriculture (SIC 01-09), Mining (SIC 10-14), Construction (SIC 15-17), and Manufacturing (SIC 20-39);
- TRA: Trade, including Wholesale Trade (SIC 50-51) and Retail Trade (SIC 52-59);
- SER: Services, defined in a broad sense, and including Transportation, Communications, Public Utilities (SIC 40-49), Finance, Insurance, Real Estate (SIC 60-67), Services (SIC 70-89), and Public Administration (SIC 90+).

The basic unit of observation is a link between sector k at location i and sector l at location j , with $k, l = (\text{RES}, \text{MAN}, \text{TRA}, \text{SER})$, and $i \neq j$. Each link is characterized by the following variables:

NC_{kilj} = number of calls from sector k at i to sector l at j ,

MS_{kilj} = number of conversation seconds from sector k at i to sector l at j ,

MC_{kilj} = total charge (\$) for all the calls/conversation seconds from sector k at i to sector l at j .

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

$$P_{kilj} = MC_{kilj} / MS_{kilj} \quad (\text{\$/second}) \quad (10)$$

As the above average price is to be used in the econometric estimations, several clarifications are necessary. A major criticism of the average price approach of

dividing revenues, R , by the quantity to be explained, Q , is that it necessarily establishes a negative relationship between Q and the computed price $P (=R/Q)$. This, of course, is fully true for local calling with only a monthly fixed charge, implying a constant price–quantity (P, Q) product, and therefore a price elasticity of -1.0 , when, in fact, the observed variations in the quantity Q are completely unrelated to the computed average price P . However, local calls are not considered in this study, which focuses on toll calling exclusively (MTS and Out-WATS). Taylor (1983), among others, has argued for the need to use elements of the rate schedule, in particular the price for the initial period as determinant of the demand for calls, and the price of an overtime period as determinant of the average duration of a call. While this is theoretically correct when analyzing the demand of individual customers facing the *same* rate schedule, one must remember that, in this study, the demands for calls and conversation minutes are aggregations of individual demands under *different* rate schedules. First, toll MTS users face three basic schedules, depending upon the time of day and day of week. Each schedule t ($=1 \rightarrow 3$) is characterized by eight distance intervals d ($=1 \rightarrow 8$), and each combination (t, d) is characterized by a fixed price for the first minute, FP_{td} , and a variable price, VP_{td} , applied to each additional minute. For any schedule t , all prices increase with distance: the maximum-to-minimum price ratio is equal to 2 for FP, and to 2.5 for VP. The daytime prices are the highest, and the evening and nighttime/weekend prices represent about [60%–70%] and [30%–40%] of the daytime prices, respectively. The normal charge of a toll call, based on the lengths of haul and conversation, may be further adjusted to account for special calling features, such as (1) operator assistance for person-to-person, collect, and person-call-back calls, (2) credit card or calling card messages, (3) calls from hotels and hospitals, etc. Second, Out-WATS users, as discussed earlier, face a completely different rate schedule, with a declining block rate structure for the variable charge, invariant with time and length of haul. As a result of this calling heterogeneity, there is no specific rate element that can be chosen as a representative price for all calls, and the average price, as calculated here, is considered the best overall representation of these different prices. For further discussion on the use of average prices, see De Fontenay and Lee (1983) and Acton and Vogelsang (1992). However, even if the estimation focus were on a specific group (e.g. daytime MTS users), it is likely that the average price for this group would still be an acceptable price representation. Indeed, an examination of the rate structure first points to extremely high correlations between FP and VP ($R=0.996$ for daytime, $R=0.990$ for evening time, and $R=0.995$ for nighttime), suggesting that using only VP would not introduce an estimation bias, as also suggested by Berndt (1984) in the case of electricity demand. As the ratio of fixed-to-variable rates is within the interval [1.5–2.0] and the overall average call duration is about 4 minutes, it is clear that the average price for such a call would be very close to the marginal (variable) price, and could be used instead of the marginal price.

The shares of the 16 sectoral combinations in terms of numbers of calls,

Table 1
Shares of intersectoral telecommunication flows (%)

Origin Sector	Destination Sector	Number of Links	Number of Calls	Conversation Seconds	Charges
RES	RES	5434	27.07	46.15	35.59
RES	MAN	1242	2.66	2.22	2.46
RES	TRA	1487	4.65	3.06	3.62
RES	SER	2571	13.05	10.12	12.53
RES	ALL	10 734	47.43	61.55	54.20
MAN	RES	1242	2.32	2.03	2.12
MAN	MAN	1064	1.83	1.27	1.64
MAN	TRA	680	1.34	0.80	1.02
MAN	SER	1043	2.65	1.83	2.34
MAN	ALL	4029	8.14	5.93	7.12
TRA	RES	1487	3.72	2.36	2.61
TRA	MAN	680	1.14	0.67	0.91
TRA	TRA	1192	3.24	2.07	2.64
TRA	SER	1068	2.73	1.75	2.31
TRA	ALL	4427	10.83	6.85	8.47
SER	RES	2571	9.71	8.24	9.02
SER	MAN	1043	2.72	1.87	2.33
SER	TRA	1068	3.09	1.94	2.44
SER	SER	3078	18.09	13.62	16.43
SER	ALL	7760	33.61	25.67	30.22

conversation seconds, and charges are presented in Table 1. The residential and service sectors (RES and SER) are by far the major producers of calls (47.43% and 33.61%) and of conversation seconds (61.55% and 25.67%). The major intersectoral interactions are RES–RES, SER–SER, RES–SER, and SER–RES, in decreasing order. Because of the simultaneous equation estimation approach used in this study, it was necessary to organize the data base by pairing each link (k, i, l, j) with the reverse link (l, j, k, i). In a few cases, there was no flow for the reverse link, i.e. $NC_{ljk i} = 0$ while $NC_{k i l j} > 0$. These cases, which represent about 3.8% of the calls and 3.6% of the conversation seconds of the initial sample, were discarded because all attempts to indirectly estimate the price variable for the link (l, j, k, i) were unsuccessful. 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 parameters. As Table 1 indicates, there are 26,950 directed links (k, i, l, j). After pairing each link with its reverse one, the final data base includes therefore 13,475 observations.

Table 2 provides further sample statistics on prices, call durations, and call distances, for each intersectoral interaction and for the whole sample. The calling distance varies between 3.8 and 160 miles, with an average of 37.4 miles. The

Table 2
Distance, price, and call duration statistics

Sectoral Interaction	Distance (miles)			Direct Flow ($k \rightarrow l$)		Reverse Flow ($l \rightarrow k$)	
	Average	Minimum	Maximum	Average Price (¢/sec.)	Average Duration (seconds)	Average Price (¢/sec.)	Average Duration (seconds)
RES(k)–RES(l)	44.5	5.1	159.9	0.42	445.3	0.46	459.3
RES(k)–MAN(l)	29.7	3.8	150.5	0.68	183.8	0.62	224.1
RES(k)–TRA(l)	32.3	5.1	148.6	0.68	171.3	0.67	173.6
RES(k)–SER(l)	39.5	5.1	155.9	0.71	185.9	0.65	233.3
MAN(k)–MAN(l)	33.5	5.1	120.2	0.63	156.0	0.79	147.6
MAN(k)–TRA(l)	33.8	3.8	148.6	0.58	147.9	0.62	137.2
MAN(k)–SER(l)	34.9	5.6	155.3	0.65	148.2	0.62	157.5
TRA(k)–TRA(l)	36.5	5.6	148.6	0.60	135.4	0.65	139.8
TRA(k)–SER(l)	35.4	5.6	132.4	0.65	146.4	0.66	141.2
SER(k)–SER(l)	39.1	3.8	139.7	0.57	174.4	0.62	175.4
Total Sample	37.4	3.8	159.9	0.61	223.7	0.61	239.3

intra-residential distance clearly stands out, with an average of 44.5 miles, followed by the intra-service and residential-service distances, above 39 miles. All other average distances are clustered within the interval [32–36] miles, except for the residential–manufacturing distance at 29.7 miles. The average call duration is by far the highest in the residential sector (459 seconds or about 7.5 minutes). The next mean duration cluster is related to calls originating and terminating at the residential sector, as well as to calls within the service sector, within the range [171–234] seconds. All other calls have mean durations within the range [135–158] seconds. Interestingly, the average charge (¢/second) is lowest for intra-residential calls, because many of them are placed in the evening or on weekends, when the lowest tariff applies, whereas all the other calls take place mostly during regular business hours, when the highest tariff applies.

Each observation in the data base characterizes the interactions between sector k at location (wire center) i and sector l at location j , and includes the following variables:

- number of calls: NC_{kilj} , NC_{ljki}
- number of conversation seconds: MS_{kilj} , MS_{ljki}
- total charge (cents): MC_{kilj} , MC_{ljki}
- average price (¢/sec.): P_{kilj} , P_{ljki}
- distance: D_{ij} ($\equiv D_{ji}$).

To the above variables we have added variables intended to measure the sizes of sector k at i and sector l at j . The size of sector (k, i) is characterized by the total

telephone flows, measured in number of calls and conversation seconds, originating and terminating at (k, i) , with:

- NCO_{ki} : total number of calls originating at (k, i)
- NCD_{ki} : total number of calls terminating at (k, i)
- MSO_{ki} : total number of conversation seconds originating at (k, i)
- MSD_{ki} : total number of conversation seconds terminating at (k, i) .

The corresponding variables for sector (l, j) are also included in each observation. Note that these total originating and terminating flows are larger than those that would be obtained by summing up flows in the sample (e.g. $MSO_{ki} > \sum_{lj} MS_{kij}$), because we have considered all flows coming out of (k, i) , even if the destination is not SIC-identified or is an 800 number. In doing so, our measures are closer to measuring the size of (k, i) . It would, of course, have been interesting to use variables independent of the data base, such as number of employees or output/revenues for sector (k, i) . This would have required a major data gathering and processing effort that was not feasible within the framework of this study.

4.2. Model specification

The number of calls, NC_{kij} , and the number of conversation seconds, MS_{kij} , can be viewed as a bidimensional characterization of the telecommunication flow variable F_{kij} in Eq. (9). Hence, this equation can be extended to the following pair of equations:

$$NC_{kij} = F(\text{Reverse Flows, Prices, Sector Sizes}) \tag{11}$$

$$MS_{kij} = G(\text{Reverse Flows, Prices, Sector Sizes}) \tag{12}$$

Next, it is assumed that:

(1) the only relevant reverse flows are those from (l, j) to (k, i) , i.e. NC_{ljk} and MS_{ljk} ;

(2) the only applicable prices are the telecommunication and transportation ones, with all other goods/service prices having negligible variations across wire centers (locations); this assumption is reasonable in view of the small size and homogeneity of the LATA;

(3) the telecommunication price is best approximated by the average charge P_{kij} , while the transportation cost proxy is the distance D_{ij} ;

(4) sector sizes are measured by the total originating and terminating flows discussed in Section 4.1. Eqs. (11) and (12) are then reformulated as follows:

$$NC_{kij} = F(NC_{ljk}, P_{kij}, D_{ij}, NCO_{ki}, NCD_{ij}) \tag{13}$$

$$MS_{kilj} = G(MS_{ljkj}, P_{kilj}, D_{ij}, MSO_{ki}, MSD_{lj}) \quad (14)$$

Because of the reverse flows, a simultaneous equation estimation approach is necessary. A linear-in-logarithms functional form is used. For each sectoral combination (k, l), two sets of two structural equations are obtained:

Number of calls

$$\begin{aligned} \ln NC_{kilj} = & a_0 + a_1 \ln NC_{ljkj} + a_2 \ln D_{ij} + a_3 \ln P_{kilj} + a_4 \ln NCO_{ki} \\ & + a_5 \ln NCD_{lj} \end{aligned} \quad (15)$$

$$\begin{aligned} \ln NC_{ljkj} = & b_0 + b_1 \ln NC_{kilj} + b_2 \ln D_{ij} + b_3 \ln P_{ljkj} + b_4 \ln NCO_{lj} \\ & + b_5 \ln NCD_{ki} \end{aligned} \quad (16)$$

Number of conversation seconds

$$\begin{aligned} \ln MS_{kilj} = & \alpha_0 + \alpha_1 \ln MS_{ljkj} + \alpha_2 \ln D_{ij} + \alpha_3 \ln P_{kilj} + \alpha_4 \ln MSO_{ki} \\ & + \alpha_5 \ln MSD_{lj} \end{aligned} \quad (17)$$

$$\begin{aligned} \ln MS_{ljkj} = & \beta_0 + \beta_1 \ln MS_{kilj} + \beta_2 \ln D_{ij} + \beta_3 \ln P_{ljkj} + \beta_4 \ln MSO_{lj} \\ & + \beta_5 \ln MSD_{ki} \end{aligned} \quad (18)$$

When the two sectors are the same ($k=l$), both equations must be identical, and the following cross-equations restrictions must apply: $a_i = b_i$ ($i=0 \rightarrow 5$) and $\alpha_i = \beta_i$ ($i=0 \rightarrow 5$).

4.3. Results

The systems of structural Eqs. (15)–(16) and (17)–(18) have 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. The results for the call equations are presented in Table 3, and those for conversation equations in Table 4. A comparison of these results with those obtained with the two-stage least squares procedure shows that (1) the conversation seconds equations are very similar in both cases, because there is very little error correlation across equations, and (2) the estimates for the call equations are often different because of significant error correlations.

Several conclusions emerge from an examination of the results in Tables 3 and 4. First, as could be expected, the effect of telephone prices is always negative and highly significant, in the inelastic range for calls and in the elastic one for conversation seconds. Second, the effect of distance is also always negative and, in most cases, highly significant. As distance is taken as a proxy for transportation

Table 3
Regression models for intersectoral calls: NC_{kij} ¹

Variable	RES-RES ²	MAN-MAN	TRA-TRA	SER-SER	RES-MAN	MAN-RES	RES-TRA	TRA-RES
Intercept	-0.364 (1.80) ³	-0.641 (2.73)	-1.375 (2.83)	-3.790 (12.35)	-0.231 (0.90)	-0.170 (0.69)	0.178 (0.63)	-0.426 (1.55)
ln NC_{ijki}	0.713 (11.85)	0.406 (4.59)	-0.306 (5.40)	-0.213 (7.03)	0.079 (0.79)	0.232 (2.78)	-0.090 (1.08)	-0.016 (0.21)
ln D_{ij}	-0.343 (4.06)	-0.178 (3.80)	-0.741 (8.69)	-0.947 (17.79)	-0.908 (9.19)	-0.677 (7.04)	-1.378 (15.38)	-1.037 (9.20)
ln P_{kij}	-0.188 (6.08)	-0.226 (5.06)	-0.226 (5.79)	-0.197 (7.52)	-0.267 (6.49)	-0.192 (5.61)	-0.196 (5.24)	-0.129 (4.66)
ln NCO_{ki}	0.113 (4.58)	0.184 (6.10)	0.484 (18.49)	0.595 (32.84)	0.282 (7.89)	0.310 (8.39)	0.379 (10.83)	0.465 (12.73)
ln NCD_{ij}	0.150 (3.62)	0.187 (5.50)	0.473 (15.15)	0.616 (31.27)	0.423 (9.37)	0.233 (7.20)	0.525 (12.51)	0.349 (10.41)
System- Weighted R^2	0.612	0.336	0.220	0.261	0.472		0.413	

Variable	RES-SER ²	SER-RES	MAN-TRA	TRA-MAN	MAN-SER	SER-MAN	TRA-SER	SER-TRA
Intercept	-2.283 (7.58) ³	-1.490 (7.44)	-1.929 (3.95)	-1.078 (3.21)	-2.753 (7.24)	-1.702 (5.50)	-1.715 (6.19)	-1.255 (4.16)
ln NC_{ijki}	-0.172 (1.93)	0.119 (3.23)	-0.212 (0.86)	0.046 (0.54)	-0.053 (0.42)	0.245 (2.81)	0.273 (2.91)	0.366 (3.89)
ln D_{ij}	1.359 (13.63)	-0.935 (18.60)	-0.725 (5.51)	-0.462 (6.29)	-0.841 (8.14)	-0.520 (6.44)	-0.582 (6.74)	-0.510 (6.04)
ln P_{kij}	-0.309 (9.12)	-0.157 (6.35)	-0.167 (2.34)	-0.190 (3.22)	-0.183 (3.78)	-0.188 (4.26)	-0.247 (5.29)	-0.211 (4.61)
ln NCO_{ki}	0.488 (12.18)	0.468 (22.21)	0.443 (5.47)	0.323 (8.59)	0.468 (7.87)	0.307 (7.23)	0.312 (7.61)	0.274 (6.53)
ln NCD_{ij}	0.693 (13.63)	0.356 (17.19)	0.512 (5.29)	0.339 (9.28)	0.527 (9.02)	0.357 (8.18)	0.343 (7.54)	0.282 (6.13)
System- Weighted R^2	0.462		0.291		0.468		0.497	

¹Number of calls from sector k at location i to sector l at location j .

²RES = Residential, MAN = Manufacturing, TRA = Trade, SER = Services.

³The t -statistics are in parentheses.

prices, this negative cross-price elasticity suggests a complementarity between the transportation and telecommunication inputs to all production processes. As distance increases, less economic transactions take place between economic agents

Table 4
Regression models for intersectoral seconds: MS_{kij} ¹

Variable	RES-RES ²	MAN-MAN	TRA-TRA	SER-SER	RES-MAN	MAN-RES	RES-TRA	TRA-RES
Intercept	-6.958 (19.76) ³	-1.617 (2.41)	-2.422 (3.84)	-5.990 (13.30)	-3.467 (6.98)	-1.900 (3.04)	-2.634 (5.73)	-2.052 (3.82)
ln MS_{ijki}	0.127 (8.30)	0.048 (1.10)	0.096 (2.12)	0.072 (2.56)	0.041 (1.34)	0.101 (2.98)	0.007 (0.21)	0.101 (2.94)
ln D_{ij}	-0.472 (13.65)	-0.062 (0.85)	-0.242 (3.16)	-0.521 (10.38)	-0.379 (6.37)	-0.452 (6.16)	-0.716 (11.71)	-0.757 (10.66)
ln P_{kij}	-1.914 (64.16)	-1.457 (20.77)	-1.485 (20.21)	-1.438 (30.16)	-1.751 (35.15)	-1.475 (25.65)	-1.616 (32.60)	-1.155 (23.87)
ln MSO_{ki}	0.522 (33.01)	0.284 (8.86)	0.359 (11.53)	0.482 (20.98)	0.333 (12.12)	0.380 (13.06)	0.362 (13.25)	0.409 (15.22)
ln MSD_{ij}	0.459 (27.34)	0.353 (10.83)	0.347 (10.37)	0.526 (22.45)	0.475 (19.51)	0.296 (8.23)	0.497 (19.94)	0.356 (11.38)
System- Weighted R^2	0.627	0.425	0.416	0.470	0.586		0.563	

Variable	RES-SER ²	SER-RES	MAN-TRA	TRA-MAN	MAN-SER	SER-MAN	TRA-SER	SER-TRA
Intercept	-5.858 (15.77) ³	-4.423 (9.76)	-2.484 (3.50)	-1.825 (2.72)	-5.109 (8.57)	-3.482 (5.26)	-3.934 (6.91)	-3.348 (5.82)
ln MS_{ijki}	0.088 (3.80)	0.099 (4.08)	0.017 (0.23)	0.286 (3.84)	0.020 (0.35)	0.088 (1.53)	0.112 (2.11)	0.186 (3.65)
ln D_{ij}	-0.603 (14.33)	-0.716 (14.58)	-0.484 (6.05)	-0.126 (1.44)	-0.653 (8.99)	-0.471 (5.69)	-0.574 (7.65)	-0.516 (7.02)
ln P_{kij}	-1.739 (46.23)	-1.332 (32.90)	-1.087 (11.67)	-1.225 (13.43)	-1.221 (16.76)	-1.138 (15.08)	-1.306 (18.48)	-1.149 (17.51)
ln MSO_{ki}	0.404 (19.43)	0.485 (21.97)	0.315 (7.35)	0.236 (5.18)	0.429 (10.92)	0.411 (9.84)	0.360 (9.98)	0.365 (10.34)
ln MSD_{ij}	0.593 (30.65)	0.429 (17.13)	0.503 (11.70)	0.282 (6.96)	0.580 (15.58)	0.422 (10.06)	0.497 (13.74)	0.407 (11.64)
System- Weighted R^2	0.622		0.403		0.472		0.482	

¹Number of conversation seconds from sector k at location i to sector l at location j .

²RES = Residential, MAN = Manufacturing, TRA = Trade, SER = Services.

³The t -statistics are in parentheses.

due to increasing transportation costs, resulting in less information exchanges. These results do not support the often-held view of telecommunication substituting for transportation, and thus leading to a new organization of economic activities

over space. However, such a general conclusion is probably unwarranted at that stage, because of the relatively short distances considered in this study, and also because the high level of activity aggregation may mask cases where indeed substitution does take place. The coefficients for the origin and destination sector size variables are all positive, as expected, and highly significant.

The call-back coefficients (i.e. the reverse flow coefficients) provide important information about the nature of the information functions associated with the intersectoral economic transactions. When this coefficient is positive, the two flows are complementary, that is, they are both necessary in contributing to the information needed to implement the transactions. When it is negative, a substitution effect takes place: there is a given, finite amount of necessary information, which may be contributed by either ends of the transaction(s). Finally, when the coefficient is zero, the information-gathering process is initiated and completed by one party only. In the case of message call-back (Table 3), complementarity characterizes the following transactions: RES↔RES (0.713), MAN↔MAN (0.406), MAN→RES (0.232), SER→RES (0.119), SER→MAN (0.245), and TRA↔SER (0.273 and 0.366). Substitution characterizes the TRA↔TRA (−0.306), SER↔SER (−0.213), and RES→SER (−0.172) transactions. In all the other cases, the coefficients are not significantly different from zero. Of particular note is the high value (0.713) of the intra-residential coefficient, that suggests that social interactions require sustained, bidirectional information exchanges. In the case of conversation seconds (Table 4), the call-back coefficients are always positive but of generally lower values than the message coefficients (mean of 0.087 and maximum of 0.286 for the TRA→MAN transaction), and a few are statistically insignificant. The differences between the call-back coefficients for the message and seconds equations suggest that the number of calls and their total length play distinct roles in the creation of the total information needed to implement economic and social transactions. Comparing these call-back coefficients to those obtained by Larson et al. (1990) for residential calling (0.75, 0.67), Appelbe et al. (1988) for total (residential + business) calling (0.38→0.72), and Martins-Filho and Mayo (1993) for total calling (0.40), suggests that using aggregate calling data may mask the considerable variability of the information constraints, as embodied in these coefficients, across economic sectors and transactions.

In order to fully assess the effects of the exogenous variables (distance, prices, sector sizes) on the endogenous variables (flows of messages and conversation seconds), it is necessary to derive the reduced-form equations from the structural equations. Consider, for instance, Eqs. (15) and (16). Eliminating $\ln NC_{ljk_i}$, we obtain:

$$\begin{aligned} \ln NC_{kilj} = & A_0 + A_1 \ln D_{ij} + A_2 \ln P_{kilj} + A_3 \ln P_{ljk_i} + A_4 \ln NCO_{ki} \\ & + A_5 \ln NCD_{ij} + A_6 \ln NCO_{ij} + A_7 \ln NCD_{ki} \end{aligned} \tag{19}$$

with:

$$A_0 = (a_0 + a_1 b_0)/\Delta, \Delta = (1 - a_1 b_1); A_1 = (a_2 + a_1 b_1)/\Delta; A_2 = a_3/\Delta;$$

$$A_3 = a_1 b_3/\Delta; A_4 = a_4/\Delta; A_5 = a_5/\Delta; A_6 = a_1 b_4/\Delta; A_7 = a_1 b_5/\Delta.$$

Similar reduced-form equations are obtained for $\ln NC_{ljk_i}$, $\ln MS_{kij}$, and $\ln MS_{ljk_i}$. The values of the coefficients of the reduced-form equations are presented in Table 5 for calls and in Table 6 for conversation seconds.

The coefficients A_i of the reduced-form equation represent the true elasticities of the dependent variable with respect to the independent ones, after the reverse flow effect has been accounted for. We further define:

$A_8 = A_2 + A_3$: the bidirectional price elasticity, which measures the percent

Table 5
Elasticities for intersectoral calls: NC_{kij}

Elasticity ¹	SECTORS							
	RES-RES ²	MAN-MAN	TRA-TRA	SER-SER	RES-MAN	MAN-RES	RES-TRA	TRA-RES
A_1	-1.195 (13.56) ³	-0.299 (4.98)	-0.567 (9.38)	-0.781 (19.36)	-0.980 (23.78)	-0.904 (21.78)	-1.287 (32.07)	-1.016 (25.66)
A_2	-0.383 (5.14)	-0.270 (5.14)	-0.250 (6.15)	-0.206 (7.63)	-0.272 (6.82)	-0.195 (5.45)	-0.196 (5.31)	-0.129 (4.64)
A_3	-0.273 (3.92)	-0.110 (3.14)	0.076 (4.43)	0.044 (5.43)	-0.015 (-0.75)	-0.063 (2.34)	0.012 (1.12)	0.003 (0.21)
A_8	-0.656 (4.59)	-0.380 (4.64)	-0.174 (5.17)	-0.162 (7.14)	-0.287 (7.47)	-0.258 (6.38)	-0.184 (5.39)	-0.126 (4.26)
A_4	0.229 (9.31)	0.220 (9.76)	0.534 (12.74)	0.623 (25.29)	0.287 (9.21)	0.316 (8.39)	0.379 (10.87)	0.465 (11.79)
A_5	0.306 (8.31)	0.224 (8.66)	0.522 (10.77)	0.645 (24.17)	0.430 (11.62)	0.237 (7.22)	0.526 (12.56)	0.350 (9.85)
A_6	0.163 (7.92)	0.089 (5.33)	-0.163 (3.98)	-0.133 (5.73)	0.025 (0.76)	0.067 (2.54)	-0.042 (1.10)	-0.006 (0.21)
A_7	0.218 (12.32)	0.091 (5.83)	-0.159 (3.76)	-0.137 (5.66)	0.019 (0.76)	0.100 (2.57)	-0.031 (1.10)	-0.009 (0.21)
A_9	0.447 (14.81)	0.311 (14.66)	0.375 (18.48)	0.486 (35.81)	0.306 (14.94)	0.416 (25.76)	0.348 (17.86)	0.456 (30.84)
A_{10}	0.469 (13.78)	0.313 (14.35)	0.359 (16.68)	0.512 (37.10)	0.455 (28.57)	0.304 (14.23)	0.484 (32.73)	0.344 (16.96)
A_{11}	0.916 (14.65)	0.624 (15.76)	0.734 (19.05)	0.998 (38.30)	0.761 (28.57)	0.720 (26.39)	0.832 (32.17)	0.800 (29.95)

Table 5. (Continued)

Elasticity	SECTORS							
	RES–SER	SER–RES	MAN–TRA	TRA–MAN	MAN–SER	SER–MAN	TRA–SER	SER–TRA
A_1	-1.174 (39.57)	-1.075 (37.41)	-0.621 (11.31)	-0.491 (9.07)	-0.803 (19.02)	-0.717 (16.33)	-0.801 (18.33)	-0.804 (16.85)
A_2	-0.302 (9.76)	-0.153 (6.03)	-0.165 (2.41)	-0.189 (3.13)	-0.181 (3.79)	-0.185 (4.11)	-0.275 (5.47)	-0.234 (4.66)
A_3	0.026 (2.29)	-0.036 (2.74)	0.040 (0.97)	-0.007 (0.49)	0.010 (0.43)	-0.044 (2.16)	-0.064 (2.23)	-0.101 (2.87)
A_8	-0.276 (9.52)	-0.189 (7.98)	-0.125 (2.02)	-0.196 (3.36)	-0.171 (3.16)	-0.229 (4.77)	-0.339 (6.39)	-0.335 (6.13)
A_4	0.478 (14.08)	0.459 (18.06)	0.439 (6.02)	0.320 (7.34)	0.462 (10.28)	0.303 (6.45)	0.346 (9.81)	0.305 (7.45)
A_5	0.679 (16.37)	0.349 (15.06)	0.507 (5.79)	0.336 (7.91)	0.520 (12.39)	0.353 (7.19)	0.382 (9.73)	0.313 (6.96)
A_6	-0.079 (2.04)	0.057 (2.98)	-0.068 (0.90)	0.020 (0.52)	-0.016 (0.43)	0.113 (2.54)	0.083 (2.44)	0.127 (3.27)
A_7	-0.060 (2.03)	0.081 (2.99)	-0.071 (0.90)	0.023 (0.52)	-0.019 (0.43)	0.127 (2.59)	0.086 (2.42)	0.140 (3.26)
A_9	0.418 (26.37)	0.540 (46.46)	0.368 (14.40)	0.343 (16.38)	0.443 (24.23)	0.430 (25.44)	0.432 (24.96)	0.445 (24.13)
A_{10}	0.600 (51.76)	0.406 (25.10)	0.439 (18.17)	0.356 (14.63)	0.504 (31.44)	0.466 (23.37)	0.465 (27.32)	0.440 (22.43)
A_{11}	1.018 (47.84)	0.946 (43.90)	0.807 (21.95)	0.699 (19.03)	0.947 (33.83)	0.896 (29.89)	0.897 (32.12)	0.885 (28.83)

¹ A_1 = total distance D_{ij} ; A_2 = own price P_{kij} ; A_3 = reverse price P_{ljk} ; $A_8 = A_2 + A_3$ = bidirectional price; A_4 = origin sector size NCO_{ki} ; A_5 = destination sector size NCD_{lj} ; A_6 = origin sector size NCO_{ij} ; A_7 = destination sector size NCD_{ki} ; $A_9 = A_4 + A_7$ = total origin sector size; $A_{10} = A_5 + A_6$ = total destination sector size; $A_{11} = A_9 + A_{10}$ = overall total sector size. ²RES = Residential, MAN = Manufacturing, TRA = Trade; SER = Services. ³The t -statistics, in parentheses, were computed according to the procedure in Goldberger et al. (1961).

change in the flow if both the direct (P_{kij}) and reverse (P_{ljk}) prices increase by one percent;

$A_9 = A_4 + A_7$: the total origin sector (k, i) elasticity under the assumption that the originating (NCO_{ki}) and terminating (NCD_{ki}) total flows are both linearly related to some unique measure of sector size (e.g. employment for an economic sector and number of households for the residential sector); then A_9 measures the percent change in the flow resulting from a one-percent increase in this sector size;

$A_{10} = A_5 + A_6$: the total destination sector (l, j) elasticity, defined under the same rationale as for A_9 , but for the destination node;

$A_{11} = A_9 + A_{10}$: the overall sector elasticity, which measures the effect of

Table 6
Elasticities for intersectoral conversation seconds: MS_{kij}

Elasticity ¹	SECTORS							
	RES-RES ²	MAN-MAN	TRA-TRA	SER-SER	RES-MAN	MAN-RES	RES-TRA	TRA-RES
A_1	-0.540 ³ (15.67)	-0.066 (0.85)	-0.268 (3.35)	-0.561 (11.69)	-0.399 (7.28)	-0.492 (7.18)	-0.722 (14.49)	-0.830 (13.75)
A_2	-1.946 (60.40)	-1.460 (20.12)	-1.499 (19.25)	-1.445 (29.02)	-1.758 (35.20)	-1.481 (25.21)	-1.617 (33.17)	-1.155 (23.12)
A_3	-0.247 (7.86)	-0.070 (1.07)	-0.144 (2.03)	-0.104 (2.47)	-0.060 (1.32)	-0.178 (2.91)	-0.008 (0.21)	-0.164 (2.84)
A_8	-2.193 (40.19)	-1.530 (13.05)	-1.643 (12.96)	-1.549 (19.82)	-1.818 (27.84)	-1.659 (20.09)	-1.625 (27.57)	-1.319 (18.42)
A_4	0.531 (35.37)	0.284 (9.02)	0.362 (12.22)	0.484 (22.30)	0.335 (12.28)	0.382 (13.18)	0.363 (13.57)	0.409 (15.22)
A_5	0.466 (29.12)	0.353 (11.08)	0.350 (10.99)	0.529 (24.00)	0.477 (20.17)	0.297 (8.27)	0.497 (20.94)	0.356 (11.38)
A_6	0.067 (9.06)	0.014 (1.16)	0.035 (2.30)	0.035 (2.76)	0.016 (1.33)	0.034 (2.90)	0.003 (0.21)	0.037 (2.86)
A_7	0.059 (9.40)	0.017 (1.15)	0.034 (2.35)	0.038 (2.75)	0.012 (1.32)	0.048 (2.93)	0.003 (0.21)	0.050 (2.90)
A_9	0.590 (42.12)	0.301 (10.69)	0.396 (14.73)	0.522 (30.96)	0.347 (13.32)	0.430 (17.48)	0.366 (15.76)	0.459 (22.15)
A_{10}	0.533 (37.32)	0.367 (12.84)	0.385 (13.99)	0.564 (33.18)	0.493 (24.33)	0.331 (8.89)	0.500 (28.41)	0.393 (13.55)
A_{11}	1.123 (45.32)	0.668 (13.39)	0.781 (15.61)	1.086 (34.33)	0.840 (24.63)	0.761 (17.78)	0.866 (27.89)	0.852 (22.28)

homothetic increases in the sizes of both the origin and destination sectors. The elasticities A_8 – A_{11} are also included in Tables 5 and 6.

Consider first the message elasticities in Table 5. The distance elasticity A_1 can be interpreted as both (1) the elasticity to transportation costs in both directions, and (2) a measure of the proximity of the telecommunication interaction, the higher its absolute value the closer the interacting parties. Clearly, residential users call in the closest proximity, with an average elasticity of -1.159 . Nonresidential users calling residential users do also call in proximity, though slightly less so, with an average elasticity of -0.998 . The lowest elasticities characterize the interactions within and among the manufacturing and trade sectors (average of -0.495). The interactions of the service sector with itself and the manufacturing and trade sectors are characterized by intermediate distance elasticities, with an average of -0.781 .

All bidirectional price elasticities A_8 are in the inelastic range. Internal residential calling appears most sensitive to price (-0.656), followed by internal manufacturing calling (-0.380), and by trade-services interactions (-0.339 and -0.335), with all other elasticities clustered in the range $[-0.125$ – $-0.287]$. As

Table 6. (Continued)

Elasticity	SECTORS							
	RES-SER	SER-RES	MAN-TRA	TRA-MAN	MAN-SER	SER-MAN	TRA-SER	SER-TRA
A_1	-0.672 (18.72)	-0.782 (18.29)	-0.488 (6.51)	-0.265 (3.41)	-0.663 (10.80)	-0.529 (8.00)	-0.645 (10.26)	-0.636 (9.80)
A_2	-1.754 (45.14)	-1.343 (32.33)	-1.093 (11.87)	-1.231 (12.74)	-1.223 (16.76)	-1.140 (14.77)	-1.334 (18.41)	-1.173 (16.95)
A_3	-0.119 (3.62)	-0.173 (3.93)	-0.021 (0.23)	-0.312 (3.58)	-0.023 (0.34)	-0.108 (1.49)	-0.131 (2.01)	-0.248 (3.42)
A_8	-1.873 (37.38)	-1.516 (25.98)	-1.114 (8.38)	-1.543 (11.78)	-1.246 (12.62)	-1.248 (12.03)	-1.465 (15.11)	-1.421 (14.45)
A_4	0.410 (19.87)	0.489 (22.69)	0.317 (8.11)	0.237 (5.17)	0.430 (11.38)	0.411 (9.90)	0.368 (10.75)	0.373 (10.76)
A_5	0.598 (32.22)	0.433 (17.40)	0.506 (13.95)	0.284 (6.92)	0.581 (16.61)	0.423 (10.12)	0.508 (15.25)	0.415 (12.11)
A_6	0.043 (3.71)	0.040 (3.95)	0.004 (0.23)	0.090 (3.45)	0.008 (0.34)	0.038 (1.51)	0.042 (2.02)	0.068 (3.39)
A_7	0.038 (3.66)	0.059 (4.00)	0.005 (0.23)	0.145 (3.68)	0.009 (0.34)	0.051 (1.51)	0.046 (2.03)	0.094 (3.47)
A_9	0.448 (24.30)	0.548 (34.36)	0.322 (9.86)	0.382 (12.70)	0.439 (16.32)	0.462 (18.90)	0.414 (16.62)	0.467 (19.18)
A_{10}	0.641 (48.23)	0.473 (20.78)	0.510 (17.06)	0.374 (11.06)	0.589 (26.13)	0.461 (15.67)	0.550 (23.07)	0.483 (18.51)
A_{11}	1.089 (44.00)	1.021 (33.86)	0.832 (16.50)	0.756 (14.73)	1.028 (25.32)	0.923 (20.84)	0.964 (23.90)	0.950 (22.88)

¹ A_1 = total distance D_{ij} ; A_2 = own price P_{kij} ; A_3 = reverse price P_{ljk} ; $A_8 = A_2 + A_3$ = bidirectional price; A_4 = origin sector size MSO_{ki} ; A_5 = destination sector size MSD_{lj} ; A_6 = origin sector size MSO_{ij} ; A_7 = destination sector size MSD_{ki} ; $A_9 = A_4 + A_7$ = total origin sector size; $A_{10} = A_5 + A_6$ = total destination sector size; $A_{11} = A_9 + A_{10}$ = overall total sector size. ²RES = Residential, MAN = Manufacturing, TRA = Trade; SER = Services. ³The t -statistics, in parentheses, were computed according to the procedure in Goldberger et al. (1961).

could be expected, the direct price elasticity A_2 is generally the dominant component of the bidirectional elasticity, except for the RES-RES and MAN-MAN interactions, because of the higher values of the call-back coefficients. The price-inelastic character of the message equations is consistent with several earlier point-to-point *message* models, including Deschamps (1974); Pacey (1983), and Guldmann (1992), as well as with several nonspatialized *message* models, including the 33 intrastate toll models reviewed by Taylor (1980) with an elasticity range $[-0.22 \rightarrow -1.04]$, the intrastate toll model of Griffin (1982) with an elasticity of -0.60 , and the intra-LATA toll model of Train (1993) with an elasticity of -0.39 . However, as discussed further on, the literature offers other *message* models that are price-elastic.

Finally, the total sector elasticity A_{11} ranges from a low of 0.624 for the MAN-MAN interaction to a high of 1.018 for the RES-SER interaction, with an overall average value of 0.842. The highest values characterize interactions

involving, at either or both ends, the residential and service sector; the lowest values characterize interactions internal to the MAN and TRA sectors, and among these two sectors. Overall, these results suggest that the flows of telephone calls increase at a lesser rate than the number of potential callers and callees at both ends of the interaction, which appears to contradict the hypothesis of access externality (Taylor, 1980). It may be that this externality characterizes local calling (which is not considered here). These results are consistent with the estimates of market size elasticities obtained in earlier studies, in particular Appelbe et al. (1988) in the range [0.38→1.49], Guldmann (1992) in the range [0.9→1.0], and Martins-Filho and Mayo (1993) in the range [0.70→0.78].

Turning now to the conversation seconds elasticities in Table 6, we see that the highest distance elasticities characterize interactions involving, at either or both ends, the RES and SER sectors, while the elasticities of the MAN–MAN, TRA–MAN, and TRA–TRA interactions are the lowest. Overall, the absolute values of the distance elasticities are smaller than those for calls, indicating that the average call duration increases with distance and confirming the telephone industry adage that “the longer the haul the longer the call.” The bidirectional price elasticities A_g vary between -1.114 and -2.193 , thus always in the elastic range. The highest elasticity (-2.193) characterizes intra-residential calling. Residential-initiated calling has the highest elasticities (average of -1.772), while the MAN–TRA, MAN–SER, and SER–MAN interactions have the lowest ones (average of -1.203). While these elasticities may appear to be large, they are in line with those of the point-to-point *message* models of Larsen and McCleary (1970) [$-0.98 \rightarrow -1.01$], De Fontenay and Lee (1983) [$-1.12 \rightarrow -1.65$], and Martins-Filho and Mayo (1993) [$-1.18 \rightarrow -1.54$], the point-to-point *minutes* models of Guldmann (1992) [$-1.43 \rightarrow -1.79$], and the aggregate, nonspatialized models of Dobell et al. (1972) [$-1.90 \rightarrow -2.57$], Davis et al. (1973) (-1.03), and Waverman (1974) [$-1.16 \rightarrow -1.35$] for Ontario/Quebec, -1.12 for the UK, and -1.08 for Sweden), where the independent variables are generally the price-deflated revenues per telephone set or per capita. However, other conversation *minutes* models, including Pacey (1983); Appelbe et al. (1988); Larson et al. (1990) and Appelbe and Dineen (1993), are price-inelastic. This variability suggests that the issue of the “correct” price elasticity of telephone demand is not settled. While Taylor (1980) has suggested that the empirical evidence points to price inelasticity, it appears that this conclusion applies mostly to message demand, and less so to minutes demand. Telephone price elasticities may very well be market- or region-specific, depending upon local economic and cultural factors, and they also appear to be very sensitive to calling distance. Thus, the search for a “unique” estimate (or range of estimates) may be illusory. Another factor that may have contributed to the higher elasticities obtained here is the fact that the telephone flows are the sum of both MTS and Out-WATS flows, and the latter have been shown by Taylor (1980) and Griffin and Egan (1985) to be in the range [$-0.86 \rightarrow -1.15$].

Overall the variability of the structural and reduced-form coefficient estimates clearly demonstrates that the role played by telecommunications in the production and socio-economic processes that take place in a regional economy is not uniform, thus warranting the disaggregate analysis implemented in this study.

5. Conclusions and areas for further research

Using a theoretical framework that considers the information flows associated with the economic and social transactions that take place among the various agents that make up a regional economy, it has been shown that the demand for telecommunications by agent A calling agent B is a function of various market prices and of various reverse calling flows towards agent A. This framework has then been used to specify and estimate, under simplifying assumptions, intersectoral, point-to-point telecommunication flow functions, making use of a very large data base on intra-LATA toll calls, where the callers and callees are identified by their SIC codes and their locations. Functions have been estimated with a simultaneous equations procedure for both numbers of calls and conversation seconds. The results show that the effects of distances, telecommunication prices, and sector sizes are always highly significant, and that the effects of reverse flows vary from positive to nil to negative. The variability of the estimates from one intersectoral interaction to another clearly justifies the selected sectoral and spatial disaggregation, which makes it possible to account for the diversity of telecommunication needs across businesses and households.

Further research should first involve the interfacing of the telephone flow data with socio-economic data (e.g. population, income, employment, sales), in order to better characterize the call originating and terminating residential and business sectors. Next, higher levels of disaggregation could be considered, in particular in terms of (1) economic sectors (e.g. one- or two-digit SIC), (2) services (e.g. MTS versus Out-WATS), and (3) time (e.g. intra-daily, weekly, monthly). Finally, more complex spatial interaction models could be estimated, that would account for the effects of spatial structure on spatial flow behavior. Variations of the traditional gravity model, based on the concepts of competing destinations (Fotheringham, 1983) and competing central places and intervening opportunities (Fik and Mulligan, 1990), could serve as starting points for these extensions.

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