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Publication Date
2008

Peer reviewed

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U.S. Consumer Expenditures Perspective, 1984–2002

Sangho Choo, Taihyeong Lee, and Patricia L. Mokhtarian

With aggregate data from the U.S. Consumer Expenditure Survey for 19 years, 1984 through 2002, this study analyzes relationships between expenditures on transportation and communications. Several classification schemes for expenditure categories were used, from the most aggregate [two categories (transportation and communications)] to the most disaggregate [nine transportation categories (new vehicle purchases, used vehicle purchases, vehicle finance charges, gasoline and motor oil, vehicle maintenance and repairs, vehicle insurance, public transportation, out-of-town lodging, and other entertainment including bikes and recreational vehicles) and five communications categories (telephone service; miscellaneous household equipment including phones and computers; television, radio, and sound equipment; postage and stationery; and reading)]. Aggregate demand system modeling (in particular, the linear approximate almost ideal demand system) was then used to determine the relationships between expenditures on transportation and those on communications, again for several different classifications. The model results indicate that transportation and communications categories have substitution and complementarity relationships, often not symmetric. However, a dominant effect of complementarity can be found in the influence of communications on transportation.

Telecommunications has been viewed as a possible substitute for travel for decades (*1*). For almost as long, however (*2*), it has been recognized that other relationships are also possible. In particular, scholars (*3*) have speculated that telecommunications and travel might stimulate each other in a relationship of mutual complementarity. In some circumstances, one type of activity might not have a significant effect on the other (e.g., when numerous e-mail messages neither stimulate nor replace travel). Alternatively, both substitution and generation effects could be at work simultaneously, with an unknown net impact (which may be near zero, making this outcome difficult to distinguish from the conceptually quite different "no impact" outcome).

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Transportation Research Record: Journal of the Transportation Research Board, No. 2010, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 121–132.
DOI: 10.3141/2010-14

Numerous empirical studies have been conducted to investigate these potential relationships. The results have been mixed, with some finding net substitution and some finding complementarity [refer to Mokhtarian and Salomon (*4*) for a review]. Most of those studies, however, have taken a disaggregate approach and have been conducted on small samples, often focusing on just a single application such as telecommuting, teleconferencing, or Internet shopping. Although a disaggregate approach is invaluable for providing behavioral insight, it is often limited in the scope of activities it can capture (the questionnaires on which such studies are often based can only be so long) and restricted to relatively small and homogeneous samples. Aggregate approaches, by contrast, can often take a more comprehensive approach to the subject at hand and apply to a much larger population.

This study takes such an approach, in which relationships between consumer expenditures on transportation and communications are investigated, using aggregate U.S. data for 1984 through 2002. The results will provide insight into the overall, net impacts of each on the other and will continue to refine understanding of this complex and important subject.

This paper is organized as follows. The next section reviews most of the other aggregate studies on this subject. The third and fourth sections describe the consumer demand modeling approach taken in this study and the available expenditure and price data, respectively. The fifth section discusses the empirical results, and the final section offers some concluding observations, including a comparison of these new results with the most closely related aggregate studies discussed in the second section.

LITERATURE REVIEW

Although numerous studies have described the overall relationships between telecommunications and travel, to date there have been only a few aggregate empirical analyses. Among them, four groups of studies—Choo and Mokhtarian (*5–7*), Lee and Mokhtarian (*8–10;* unpublished data, 2005), Plaut (*11, 12*), and Selvanathan and Selvanathan (*13*)—are especially worthy of detailed discussion. The first one focuses on the actual activities of traveling and telecommunicating, and the other three take economic perspectives but focus on different aspects of the subject. An aggregate study generally reveals only the net impact of one variable on another instead of the detailed components (e.g., substitution in some respects, complementarity in others) of that impact.

Activity-Based Measures

Choo (*5*) explored the aggregate relationships (substitution, complementarity, or neutrality) between telecommunications and travel and compared those relationships across transportation modes. This study first presents a conceptual model, considering causal relationships among travel, telecommunications, land use, economic activity, and sociodemographics. Then, with the conceptual model, the aggregate relationships between telecommunications (local telephone calls, toll calls, and mobile phone subscribers) and travel (vehicle miles traveled, transit passengers, and airline passenger miles traveled) are explored in a comprehensive framework, using structural equation modeling of U.S. national time series data spanning 1950–2000. At the most detailed level, individual and joint structural equation models for telecommunications and ground travel or airline travel are developed by using selected subsets of the endogenous variables; then the causal relationships between the two are compared by mode. The results (*7*) indicate that most significant causal relationships between telecommunications and travel are mutually complementary. That is, as telecommunications demand increases, travel demand increases, and vice versa. The only exceptions are the two causal relationships between transit passengers and mobile phone subscribers, which are substitutive. Furthermore, there are a number of neutral (zero net) effects of telecommunications on travel and vice versa. Overall, causal effects between telecommunications and travel differ depending on the modes involved. However, most of them are complementary regardless of the causal direction.

At a less detailed level, composite indices for eight endogenous variable categories were constructed by combining the multiple variables representing a given category into a single composite indicator for that category through confirmatory factor analysis. Then, structural equation models for travel and wired (telephone calls) or mobile (mobile phone subscribers) telecommunications were estimated, using the composite indices and sociodemographic variables (*6*). The estimated models also support the hypothesis that the aggregate relationship between actual amounts of telecommunications and travel is complementarity, albeit asymmetric in directional weight. That is, as travel demand increases, telecommunications demand increases, and (to a lesser extent) vice versa. Consequently, the empirical results from both levels of structural equation modeling strongly suggest that the aggregate relationship (or systemwide net effect) between actual amounts of travel and telecommunications is complementarity, not substitution.

Monetary-Based Measures

Industrial Perspective

Plaut (*11*) pointed out that industry accounted for about two-thirds of total monetary expenditures on transportation and communications in the European Community (as the predecessor to the European Union was known). Using input–output (I-O) analysis, she examined the relationships between transportation and communications as inputs to 44 industry groups (including transportation and communications) for nine countries of the European Community in 1980. She found generally positive correlations between transportation and communications across industries. That is, for the 44 industry groups overall, when expenditures on communications inputs were high, spending on transportation inputs also tended to be high, and conversely. She concluded that there was a complementary relationship between communication and travel, at least for the industrial context.

Later, Plaut (*12*) investigated the relationship between communications and transportation in Israel (in 1988), Canada (in 1991), and the United States (year not clearly specified). Her findings include complementary relationships for all the countries analyzed in the paper, although the format of the I-O accounts is different because each country uses a different set of industry categories.

Building and expanding on Plaut's work, Lee and Mokhtarian (*8, 9*) explored the aggregate relationships between transportation and communications as industrial inputs in the United States, using benchmark I-O accounts provided by the Bureau of Economic Analysis of the U.S. Department of Commerce. The study analyzed Spearman correlations between transportation and communications for each of 10 benchmark years from 1947 to 1997. They investigated not only the utilities (U) sectors (i.e., services) of transportation and communications, but also the manufacturing (M) sectors (i.e., goods) for those inputs, whereas previous studies analyzed only utilities. They compared results over time based on five sets of correlations between transportation and communications [M-M, M-U, U-M, U-U, and (M + U)–(M + U)] using direct I-O accounts. (Direct I-O accounts refers to the input coefficient matrices, which are commodity-by-industry direct requirements; that is, the *i-j*th input coefficient represents the monetary value of inputs of commodity *i* that are required to produce a dollar of gross output in industry *j*.) They found a pattern of predominant complementarity for the manufacturing pair (M-M) and substitution for the utilities pair (U-U). For the other pairs, there is complementarity between transportation manufacturing and communications utilities and substitution between transportation utilities and communications manufacturing as well as between transportation and communications overall, although the first and last of those results are somewhat weakly based on only four significant correlations out of 10. There are intriguing indications of a possible structural change from substitution to complementarity for the three pairs showing mainly substitution effects (the utilities pair, transportation utilities–communications manufacturing pair, and "all" pair), beginning around 1987.

Lee and Mokhtarian (*10;* unpublished data, 2005) analyzed the relationship between transportation and communications using total I-O accounts. [Total I-O accounts refers to industry-by-commodity total requirements; the *i-j*th total requirement coefficient represents the dollar-valued change in output in industry sector *i* resulting from a unit ($1.00) change in the final demand for commodity *j*.] They found two patterns: the first pattern exhibits uniform complementarity and applies to the manufacturing pair (M-M), and the second pattern shows a run of substitution effects followed by a run of complementarity effects and is exhibited by the remaining four pairs [M-U, U-M, U-U, and (M + U)–(M + U)].

Consumer Perspective

Selvanathan and Selvanathan (*13*) estimated a simultaneous equation system (a Rotterdam demand system) of consumer demand calibrated with annual, per capita consumption expenditures and population time series data (1960–1986) for the United Kingdom and Australia. They examined four sectors of consumer demand—private transportation, public transportation (PT), communications, and all others—and found that private transportation, PT, and communications have pairwise relationships of substitution, showing all positive cross-price elasticities among those three (meaning that an increase in the price of one type of good increases the consumption of the other types).

The Plaut (*11, 12*) and Selvanathan and Selvanathan (*13*) studies show opposite relationships between transportation and communications. This is not necessarily surprising because they involve different sectors (industry and consumer), methodological approaches (I-O analysis and consumer demand modeling), treatment of time (cross section and time series), study period (1980 and 1960–1986), and geographic locations (Europe and Australia and the United Kingdom). To eliminate some of those potential sources of differences between the two, it would be desirable to replicate their approaches for the same geographic area during the same time period. The Lee and Mokhtarian (*8–10;* unpublished data, 2005) studies discussed in the previous subsection replicate (and extend) the Plaut approach in the United States for 1947–1997, whereas the present study essentially replicates the Selvanathan and Selvanathan methodology in the United States for 1984–2002. Thus, it will be interesting to compare the findings of the present study with those of Selvanathan and Selvanathan (similar methodology; different countries and earlier time frame) and Lee and Mokhtarian (same country, heavily overlapping time frame; industrial versus consumer perspective).

METHODOLOGY

To estimate aggregate consumer demand functions, this study uses the linear approximate almost ideal demand system (LA/AIDS) (*14*) because it is theoretically and practically reasonable and easily interpretable (*15, 16*). The general form of the LA/AIDS model is as follows:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \beta_i \ln(X/P^*) \qquad i = 1, 2, \ldots, k$$

where

$$w_i = \frac{p_i q_i}{\sum_j p_j q_j} = \text{(current dollar) expenditure share of good } i,$$

p_i = price of good *i*,

q_i = quantity demanded of good *i*,

$X = \sum_j p_j q_j$ = total expenditure on all goods (often treated as synonymous with income), and

P^* = Stone's price index defined as

$$\ln P^* = \sum_j w_j \ln p_j \qquad j = 1, 2, \ldots, k$$

According to consumer (price) theory, the following adding up, homogeneity, and symmetry restrictions should hold:

adding up:

$$\sum_i \alpha_i = 1$$

$$\sum_i \gamma_{ij} = 0$$

and

$$\sum_i \beta_i = 0$$

homogeneity:

$$\sum_j \gamma_{ij} = 0$$

and

symmetry:

$$\gamma_{ij} = \gamma_{ji}$$

The adding-up constraint ensures that the expenditure shares w_i sum to 1. Homogeneity means that an increase in income and all prices by the same factor should leave the optimum solution unchanged (e.g., the same optimum quantities would be demanded if income and prices both doubled). Symmetry means that the impact on the quantity demanded of good *i* of a unit increase in the price of good *j* should equal the impact on the quantity of *j* of a unit increase in the price of *i.*

Generally, three types of elasticities of demand can be calculated in the LA/AIDS: income elasticity and the two price elasticities known as Marshallian (uncompensated) and Hicksian (compensated):

- Income (expenditure) elasticity: $e_{\text{income},i} = (\beta_i/w_i) + 1$,
- Marshallian (price) elasticity: $e_{ij}^M = -\delta_{ij} + (\gamma_{ij}/w_i) - \beta_i(w_j/w_i)$, and
- Hicksian (price) elasticity: $e_{ij}^H = e_{ij}^M + w_j e_{\text{income},i} = -\delta_{ij} + (\gamma_{ij}/w_i) + w_j$

where δ_{ij} is the Kronecker delta ($\delta_{ij} = 1$ if $i = j$, and 0 otherwise). The Marshallian price elasticity reflects both substitution and income effects, whereas the Hicksian price elasticity accounts for the substitution effect only. Thus, the compensated demand is more sensitive to price changes than uncompensated demand. The three elasticities are functions of the parameters being estimated (βs and γs), so they can be statistically tested. For ease of reference, a typology of income and price elasticities is presented in Table 1.

In this study, unconstrained models are estimated, and then the homogeneity and symmetry restrictions are tested. Additionally, the expenditures and both types of price elasticities are calculated and compared. Each set of models is estimated without and with a time trend variable, *t,* in each equation, in the latter case to capture average changes in taste over time [see Blanciforti and Green (*14*) for another application of this approach].

DATA DESCRIPTION

Generally, expenditure shares (w_i) and prices (p_i) are needed to estimate LA/AIDS models. They can be obtained from consumer expenditure data and consumer price index (CPI) data. The data for this study range from 1984 to 2002 (19 years) because of compatibility and availability issues for years outside that range.

Consumer Expenditure Data

The Bureau of Labor Statistics (BLS) publishes expenditure data for goods and services through consumer expenditure surveys. As indicated in Figure 1, this study started with the two broadest conceptual categories of transportation and communications; they were split into smaller groups following the categorization structure available in the data. Finally, nine items closely related to transportation

TABLE 1 Typology of Elasticities

Condition	Name	Explanation
Expenditure (income) elasticities		
$e > 0$	Normal good	As income rises, so does the quantity demanded.
$e > 1$	Luxury	As income rises, the quantity demanded increases by a greater proportion.
$0 < e < 1$	Necessity	As income falls, the quantity demanded decreases by a smaller proportion.
$e < 0$	Inferior good	As income rises, the quantity demanded falls.
Price elasticities (uncompensated)		
Own		
$e < 0$	(Usual case)	As the price of a good increases, the quantity demanded of it decreases.
$e > 0$	Veblen or Giffen good	As the price of a good increases, so does the quantity demanded of it, indicating a status effect (Veblen) or a good essential to subsistence (Giffen).
Cross		
$e > 0$	Substitution	As the price of one good increases, the quantity demanded of another good increases.
$e < 0$	Complementarity	As the price of one good increases, the quantity demanded of another good decreases.
Any elasticity		
$\|e\| < 1$	Inelastic	The demand response is proportionately smaller than the income or price change.
$\|e\| > 1$	Elastic	The demand response is proportionately larger than the income or price change.
$\|e\| = 1$	Unit-elastic; unitary elasticity	The demand response is proportional to the income or price change.

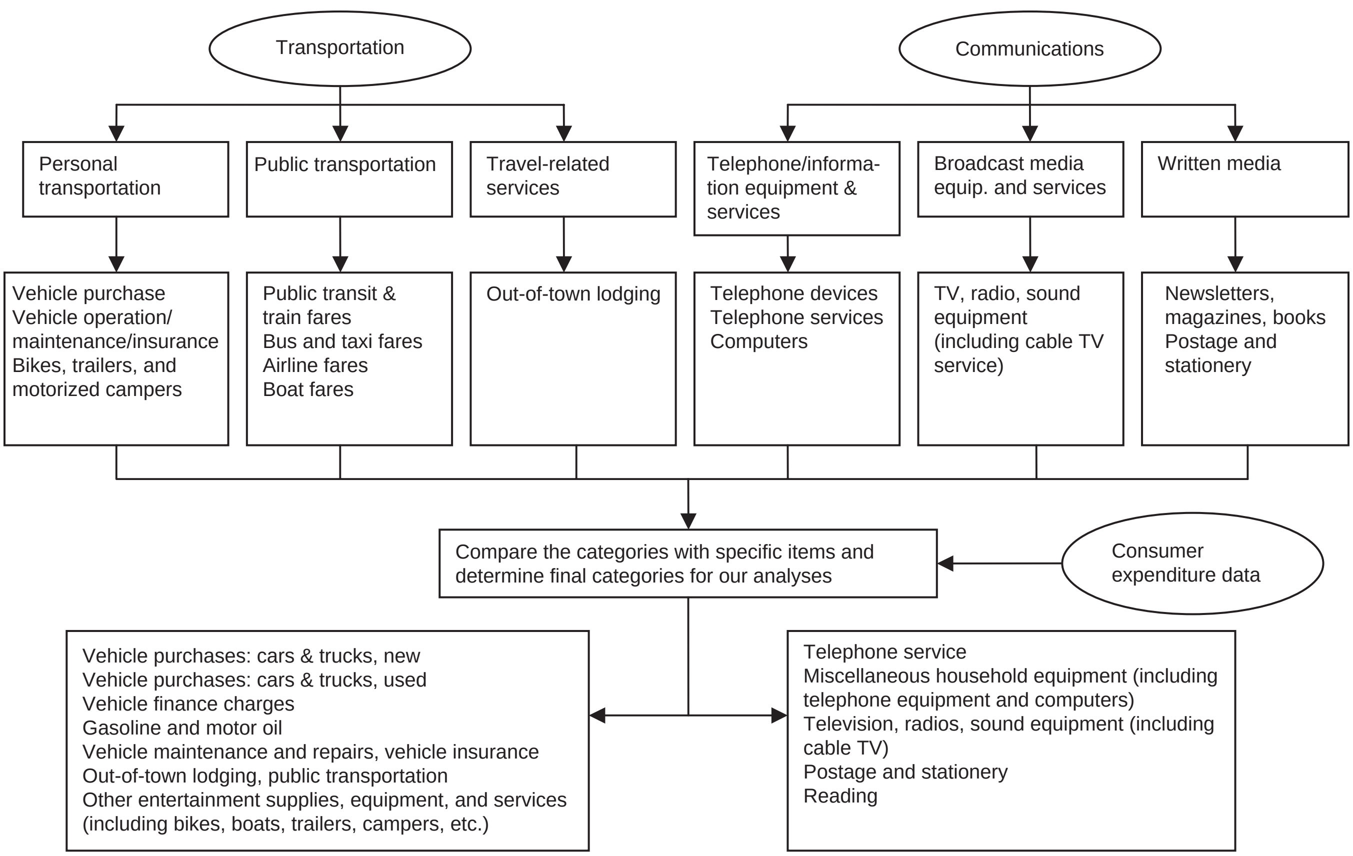


FIGURE 1 Selection procedure for transportation and communications items.

and five items associated with communications were identified. Brief explanations of each item category are presented. The explanations are excerpted from the glossary available on the BLS website (www.bls.gov/cex/csxgloss.htm). Goods that are closely related to transportation and communications are not always classified into individual categories, and so several categories include other goods. However, they are included because many of their constituent items relate to transportation and communications. For example, the "out-of-town lodging" category is identified as a transportation item in this context, because lodging away from home (including vacation home, hotel, and motel expenditures) is likely to be associated with transportation. The "other entertainment equipment" category is also included under transportation because it includes bicycles and a number of other recreational travel vehicles (as well as other less relevant items).

Transportation

- Out-of-town lodging. All expenses for homes, school, college, hotels, motels, and other lodging while people are out of town. Primary residence expenses are included elsewhere and are not analyzed here.
- Other entertainment supplies, equipment, and services. Indoor exercise equipment, athletic shoes, bicycles, trailers, purchase and rental of motorized campers and other recreational vehicles, camping equipment, hunting and fishing equipment, sports equipment (winter, water, and other), boats, boat motors and boat trailers, rental of boats, landing and docking fees, rental and repair of sports equipment, photographic equipment and supplies (film and film processing), photographer fees, repair and rental of photo equipment, fireworks, and pinball and electronic video games.
- PT. Fares for mass transit, buses, trains, airlines, taxis, school buses for which a fee is charged, and boats.
- Vehicle purchases—cars and trucks, new. Purchase of new domestic and imported cars and trucks and other vehicles, including motorcycles and private planes.
- Vehicle purchases—cars and trucks, used. Purchase of used domestic and imported cars and trucks and other vehicles, including motorcycles and private planes.
- Vehicle finance charges. Dollar amount of interest paid for a loan contracted for the purchase of vehicles (new or used, domestic or imported, cars and trucks and other vehicles, including motorcycles and private planes).
- Gasoline and motor oil. Gasoline, diesel fuel, and motor oil.
- Vehicle maintenance and repairs. Tires, batteries, tubes, lubrication, filters, coolant, additives, brake and transmission fluids, oil change, brake work including adjustment, front-end alignment, wheel balancing, steering repair, shock absorber replacement, clutch and transmission repair, electrical system repair, exhaust system repair, body work and painting, motor repair, repair to cooling system, drive train repair, drive shaft and rear-end repair, tire repair, audio equipment, other maintenance and services, and automobile repair policies.
- Vehicle insurance. Premium paid for insuring cars, trucks, and other vehicles.

Communications

- Telephone service. All charges related to telephone calls (equipment not included).
- Miscellaneous household equipment. Typewriters, luggage, lamps and light fixtures, window coverings, clocks, lawnmowers and gardening equipment, other hand and power tools, telephone answering devices, telephone equipment and accessories, computers and computer hardware for home use, computer software and accessories for home use, calculators, business equipment for home use, floral arrangements and house plants, rental of furniture, closet and storage items, other household decorative items, infants' equipment, outdoor equipment, smoke alarms, other household appliances, and other small miscellaneous furnishings.
- Television, radios, sound equipment. Television sets, video recorders, video cassettes, video tapes, discs, disc players, video game hardware, video game cartridges, cable TV, radios, phonographs, tape recorders and players, sound components, records, compact discs and tapes, musical instruments, and rental and repair of TV and sound equipment.
- Postage and stationery. All types of postage and stationery supplies.
- Reading. Subscriptions for newspapers and magazines; books through book clubs; and purchase of single-copy newspapers, magazines, newsletters, books, and encyclopedias and other reference books.

Consumer Price Index Data

The CPI is a measure of the average change in the prices of a market basket (i.e., a representative sample) of consumer goods and services. Generally, BLS collects price data monthly for all items, based on outlet surveys (including retail stores and service establishments) obtained through personal visits or telephone calls by BLS trained representatives. Then, BLS publishes CPI data for all urban consumers (CPI-U) and for urban wage earners and clerical workers every month. The CPI-U measures are used for this study, as they are most closely congruent to the population represented by the national consumer expenditure survey data.

CPI categories associated with transportation and communications were selected, considering the consumer expenditure categories discussed previously. CPIs for most categories are available for the study period 1984 through 2002. However, some categories were added or reclassified into new or other categories in 1998, so their data are not completely available. Further, the CPI for automobile finance charges is not published after 1997. The relative importance of each category in the CPIs is used to extrapolate CPIs for the missing years of "automobile finance charges" and "information technology, hardware, and services" and to create combined CPI categories to match the consumer expenditure categories (as well as the other categories introduced later). Hereafter relative importance is designated "weight"; for example, the weight of the CPI for food is 16.19, which means the price of all food items constitutes 16.19% of the price of all items (i.e., the price of the entire market basket). The weight data for 1984 and 1985 are not available, so they were extrapolated by using local or global regression analyses (with year as the explanatory variable) or by taking average values of slopes after examining their scatter plots. For additional details on these and other aspects of the study, refer to Choo et al. (*17*).

Because the published categories for consumer expenditures and the CPI are not exactly the same, it is necessary to reconcile them. This study focuses more on consumer expenditures (as measures of consumer demand) than on the CPI, so CPI categories should be combined based on the consumer expenditure categories (nine transportation and five communications categories). Composite CPIs are required not only for the categories indicated in Table 2 (the 13 categories in the table are not modeled directly because of the small sample size of the data set) but also when groups of the 14 categories are combined.

The weights of items composing a CPI are used to create composite CPIs. There are two logical ways a composite CPI for a combined category k, CPI_k, can be defined:

using the corresponding CPIs:

$$\text{CPI}_k = \sum_i w_{ik}\text{CPI}_{ik} \Big/ \sum_i w_{ik}$$

using the CPI for all items:

$$\text{relative CPI}_k = \sum_i w_{ik}\text{CPI}_{\text{all}} \Big/ \sum_k \sum_i w_{ik} = \sum_i w_{ik}\text{CPI}_{\text{all}} \Big/ 100$$

The first definition can be viewed as a bottom-up approach that builds a composite CPI from the CPIs for the constituent items in the category, whereas the second definition reflects a top-down approach that partitions the overall CPI based on the combined importance weights of the items in each composite category. Thus, the first measure is simply a weighted average of the individual CPIs for the items composing the category, where the weights are the relative importance of each item to the overall market basket. The second measure simply calculates the portion of the overall CPI that is attributable to the category based on the relative importance of all items in the category. It is then necessary to rescale the relative CPI_k by setting the relative CPI_k of the base year to 100 (and thus the two CPI formulations cannot be directly compared until that rescaling has been accomplished). These two types of composite CPIs are used and compared in the demand system models presented in the following section.

LA/AIDS MODELING

Model Specification

As discussed in the previous section, there are nine and five subcategories for transportation and communications, respectively. The data on these variables are available only from 1984 to 2002 (19 years of observations). The expenditure share for the numeraire (other) category is calculated by subtracting the sum of the expenditure shares of all transportation and communications categories from 1. Because price and quantity data for all goods are not available, in keeping with common practice (*18, 19*), CPI data (specifically, the two different sets of composite CPIs obtained by the different weighting schemes described in the preceding section) are used for the price variables in the LA/AIDS models. Additionally, a CPI was created for the "other" category using its relative importance among the CPIs.

On the basis of the various conceptual groupings for the 14 communications and transportation categories, six alternative grouping schemes were developed for the communications and transportation categories. All 14 categories were not considered as an alternative. In practical terms, 14 equations (not counting the "other" category) cannot be estimated simultaneously, because the data have only 19 years of observations and the number of parameters to be estimated in an LA/AIDS model would exceed the number of observations.

As indicated in Figure 2, the 14 categories were classified into two to six groups. The classifications are conceptually reasonable and meaningful for exploring relationships between transportation and communications by level and type of aggregation. For example, Alternative 1 has the most aggregate categories (transportation and communications), whereas Alternative 4 has the most disaggregate categories [entertainment; out-of-town lodging together with PT, personal vehicle (PV) capital, and operation; and new and old communications technologies]. The first four groups of Alternative 4 are related to transportation and the last two are related to communications. But, the "other entertainment equipment/service" category is excluded in Alternative 5, and both the "other entertainment

TABLE 2 Correspondence Between Consumer Expenditure and CPI Categories

Consumer Expenditure	Consumer Price Index
Transportation	
Out-of-town lodging	Combined CPI of housing at school, excluding board, and other lodging away from home including hotels and motels
Vehicle purchases: cars and trucks, new	New vehicles
Vehicle purchases: cars and trucks, used	Used cars and trucks
Gasoline and motor oil	Motor fuel
Vehicle finance charges	Automobile finance charges
Vehicle maintenance and repairs	Combined CPI of motor vehicle maintenance and repair and motor vehicle parts and equipment
Vehicle insurance	Motor vehicle insurance
Public transportation	Public transportation
Other entertainment supplies, equipment, and services	Sporting goods
Communications	
Telephone	Combined CPI of land-line telephone services, local charges, intrastate toll calls, and interstate toll calls (but not wireless services)
Postage and stationery	Postage (but not delivery services)
Miscellaneous household equipment	Information technology, hardware, and services (information processing equipment before 1998)
Television, radios, and sound equipment	Combined CPI of televisions, cable and satellite television and radio service, and audio equipment
Reading	Recreational reading materials

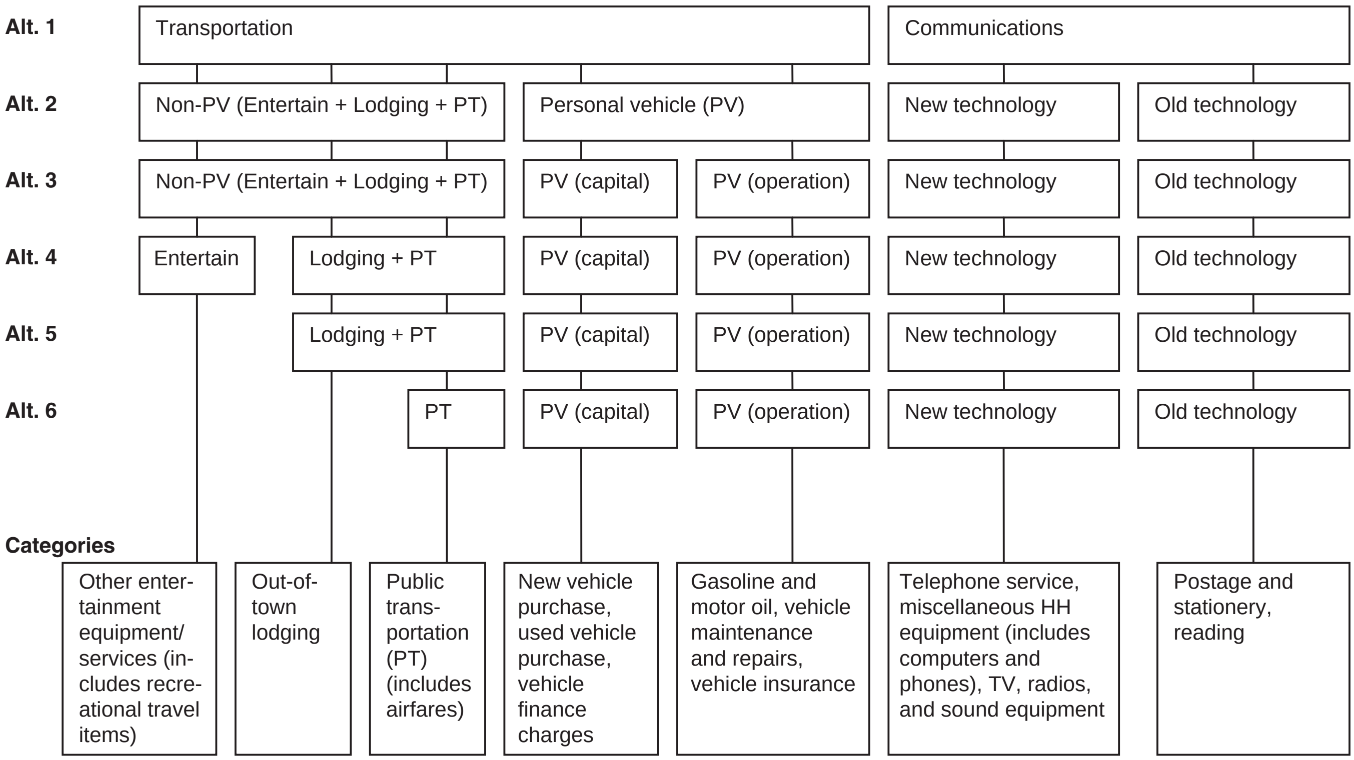


FIGURE 2 Alternative grouping schemes for transportation and communications categories.

equipment/service" category and the "out-of-town lodging" category are excluded in Alternative 6 to explore relationships between pure vehicle-travel-related categories and communications. Figure 3 presents the transportation and communications expenditure share trends for Alternatives 1 and 4.

LA/AIDS models were estimated for the six alternatives and expenditure, own-price, and cross-price elasticities were calculated. SAS 8.0 was used for model estimation, with the iterative seemingly unrelated regression estimation method. This method makes it easy for users to test the homogeneity and symmetry of the models.

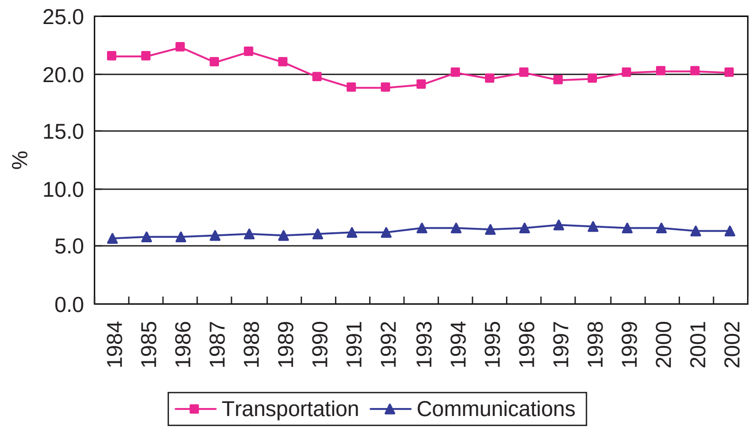
Model Results

For model estimation, the equation for the "other" category was deleted in each LA/AIDS model to achieve the adding-up restriction. Although the parameters of the deleted equations can be obtained manually through the adding-up condition, their parameters are not presented here because the focus is on relationships between communications and transportation. The parameters of the LA/AIDS model for each alternative were first estimated, and then expenditure and price elasticities were calculated at mean values of expenditure shares. All model results are presented for the two different types of composite CPIs that were computed: individual and (CPI all based) weighted CPIs. Their parameter estimates are occasionally different with respect to signs and statistical significances because of differences in their trends. In view of the small sample size, the relatively liberal standard p value of <0.1 was adopted as the threshold for statistical significance.

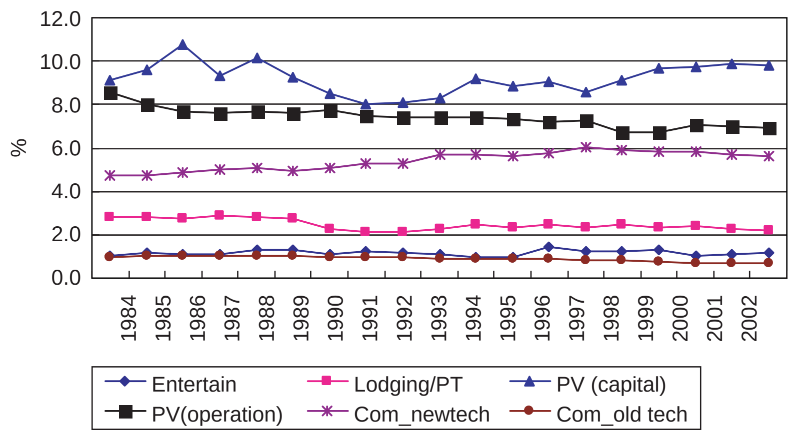
The utility and demand theory–based symmetry and homogeneity restrictions were tested for all alternatives using F-tests. Most AIDS models rejected the restrictions, although the most aggregate alternatives (with the fewest equations in their systems) did not always reject the restrictions. Many empirical studies [including the foundational one of Deaton and Muellbauer (*20*)] reject both conditions, possibly because the symmetry and homogeneity restrictions are satisfied only in a steady-state situation (*21*). Because these models are based on time series data (which are dynamic), the model results obtained without imposing the restrictions are presented, as is often done (*18*).

A previous paper (*22*) presented the results from one set of models (Alternative 3) in detail. Here, a higher-level summary of the results across all alternatives is presented. The focus is on the significant expenditure and price elasticities estimated from the AIDS models instead of on the estimated parameters of each model. Although all elasticities are briefly discussed, the cross-price elasticities showing the relationships between transportation and communications are of particular interest.

Table 3 presents a summary of expenditure and (own and cross) price elasticities for all alternatives. All expenditure (income) elasticities are positive, indicating that all transportation and communications categories studied here are normal goods. Most transportation categories (entertainment, out-of-town lodging, PT, and PV capital) are highly income elastic (luxuries) except for the PV operation category, which is income inelastic (a necessity). This indicates that once a consumer acquires a vehicle, there is a demand for the goods and services needed to operate it, regardless of change in income. Communications categories are sometimes income inelastic but in any case are generally less elastic than transportation ones, indicating that communications is more essential than travel. The old communications technology category (printed media and postage) is more income elastic than the new technology one (electronic communication goods and services), especially in the weighted CPI models.



(a)



(b)

FIGURE 3 Transportation and communications expenditure share trends: (*a*) Alternative 1 (two categories), and (*b*) Alternative 4 (six categories).

As expected, own-price elasticities are generally negative where they are significant. Also, they are often insignificant, indicating insensitivity to price. On the other hand, some positive, significant results (PV capital in Alternative 4 or transportation overall in Alternative 1) could reflect changing tastes. Similar to expenditure elasticities, transportation categories are generally more price elastic than communications categories.

With respect to within-category cross-price elasticities, transportation categories have both substitution and complementarity relationships, whereas the two communications categories have a substitution relationship. Substitution relationships are identified in the following pairwise transportation categories:

- PV and non-PV categories (Alternative 2),
- PV capital and non-PV categories (Alternative 3),
- PV capital and lodging and PT categories (Alternative 4),
- Lodging and PT categories and PV capital or PV operation (Alternative 5), and
- PT and PV capital or PV operation (Alternative 6).

Complementarity relationships are significant for the following pairs of transportation categories:

- PV operation and non-PV (Alternatives 3 and 4),
- PV operation and PV capital (Alternatives 3, 4, 5, 6),
- Entertainment and non-PV (Alternative 4),
- Entertainment and PV capital (Alternative 4),
- PV operation and lodging and PT (Alternative 5).

New and old technology communications categories have substitution relationships for all alternatives except Alternative 1 (in which they are not distinguished).

With respect to between-category cross-price elasticities (the main focus of this study), transportation and communications categories have both substitution and complementarity relationships. Table 4 presents a detailed summary of the significant relationships between transportation and communications categories for all alternatives, including the results for a parallel set of equations containing a time trend. Both sets of results are similar, but more significant relationships are found in the models without a time trend.

In the model without the time trend, substitution in the impact of transportation on communications (i.e., the substitution of communications as the price of travel increases) is found at the most aggregate level (two categories). This illuminates not only the results of this study but the comparable one (substitution between transportation and communications at an aggregate level of classification) of Selvanathan and Selvanathan (*13*). However, the two-category model with the time trend shows complementarity in the impact of communications on transportation (i.e., generation of travel as the

TABLE 3 Summary of Expenditure and Price Elasticities

Effect	Model Alternatives 1	2	3	4	5	6
Expenditure (income) elasticities						
Transportation						
Elastic ($e > 1$; luxury)	√	√	√	√	√	√
Inelastic ($0 < e < 1$; necessity)			√	√	√	√
Communications						
Elastic ($e > 1$; luxury)		√	√	√	√	√
Inelastic ($0 < e < 1$; necessity)	√	√	√	√	√	√
Own-price elasticities						
Transportation						
Elastic ($e < -1$)[a]	√	√	√	√	√	√
Inelastic ($-1 < e < 0$)		√	√	√	√	√
Communications						
Elastic ($e < -1$)	√			√		√
Inelastic ($-1 < e < 0$)	√	√	√	√	√	√
Cross-price elasticities (within category)						
Transportation						
Substitution ($e > 0$)	n/a	√	√	√	√	√
Complementarity ($e < 0$)	n/a		√	√	√	√
Communications						
Substitution ($e > 0$)	n/a	√	√	√	√	√
Complementarity ($e < 0$)	n/a					
Cross-price elasticities (between categories)						
Transportation-communications						
Substitution ($e > 0$)	√	√	√	√	√	√
Complementarity ($e < 0$)		√	√	√	√	√

NOTE: Only significant elasticities are considered.
n/a = not applicable.
[a]The Hicksian transportation own-price elasticity in the individual CPI-based model for Alt. 1 is positive, significant, and greater than 1; however, both Marshallian and Hicksian own-price elasticities in the weighted CPI-based model for Alt. 1 are negative, significant, and less than –1. Both Marshallian and Hicksian own-price elasticities for PV-cap in the weighted CPI-based model for Alt. 4 are positive and significant. Own-price elasticities for PV-cap in all other models are sometimes positive and sometimes negative, but not significant. All other significant own-price elasticities for transportation categories are negative.

price of communication decreases). Both results are plausible: communication media do have the ability to obviate the need to travel (and thus can replace travel as it becomes more expensive), but they can also stimulate the desire to travel (and thus when their prices fall, more communication occurs, which leads to more travel).

Both types of relationships continue to surface for finer disaggregations of the two main categories, but the dominant relationship is complementarity, with or without the time trend. For example, 72 of the relationships summarized in Table 3 are complementarity, compared with only 30 demonstrating substitution. Interestingly, the predominant nature of the relationship differs depending on the direction. With respect to the influence of communications on transportation, complementarity overwhelmingly dominates, accounting for 56 of 66 significant relationships across all models. With respect to the influence of transportation on communications, however, the two types of relationships are more evenly distributed: substitution dominates, with 20 significant relationships, but complementarity is also strongly present, with 16 significant relationships. The fact that there are far fewer significant relationships in this direction (36 in all) compared with the communications → transportation direction (66) may indicate that both complementarity and substitution effects are present and counteracting each other more often in the transportation → communications direction. From the standpoint of promoting communications as a replacement for travel, however, it is unfortunate that the larger number of significant relationships in the communications → transportation direction are of the "wrong" kind: complementarity, leading to more travel instead of less.

CONCLUSIONS

Using aggregate data from the U.S. Consumer Expenditure survey for the 19 years 1984–2002, this study analyzes relationships between expenditures on transportation and communications. The central question of interest is, with respect to consumer expenditures, do transportation and communications tend to be substitutes, complements, or neither? Although this question has been explored in a number of disaggregate studies focusing on a single application such as telecommuting, there are relatively few studies addressing it at the aggregate level, using comprehensive measures comprising all aspects of transportation and communications.

Several classification schemes were used for expenditure categories, from the most aggregate [two categories (transportation and communications)] to the most disaggregate [nine transportation categories (new vehicle purchases, used vehicle purchases, vehicle finance charges, gasoline and motor oil, vehicle maintenance and repairs, vehicle insurance, PT, out-of-town lodging, and "other entertainment" including bikes and recreational vehicles) and five communications categories (telephone service; miscellaneous household equipment including phones and computers; television, radio, and sound equipment; postage and stationery; and reading)].

Then, aggregate demand system modeling (in particular, the LA/AIDS model) was used to determine the relationships between expenditures on transportation and those in communications, again for several different classifications. The model results indicate that transportation and communications have both substitution and complementarity relationships, often not symmetric. However, with respect to the influence of communications on transportation, the dominant effect is complementarity.

One limitation of this study is that some items other than transportation and communications are embedded in a few of the expenditure categories used. However, such items appear to comprise only small proportions of the total expenditures in the associated categories, so their effects on the model interpretation are expected to be small. Another limitation is that the time series ends in 2002, with considerable development in communications technology and applications continuing beyond that point. Clearly, it will be desirable to revisit this study in several years, to ascertain whether its findings still hold.

Table 5 compares this study with the previous most relevant aggregate ones. Turning first to the two consumer-demand studies on the right-hand side of Table 4, some similarities can be observed. Both studies found public and private transportation to be substitutes, and, consistent with the result for Selvanathan and Selvanathan's more aggregated categories, this study found the influence of transportation on communications to be a substitution effect more often than not (although often insignificant, hinting at both substitution and complementarity effects often nearly canceling out). In contrast to Selvanathan and Selvanathan, however, this study found strong evidence of a complementary influence of communications on transportation. It is interesting that price elasticities in the communications → transportation direction (while still positive, indicating substitution) are far weaker for Selvanathan and Selvanathan than the elasticities in the transportation → communications direction. This would be true if a substantial complementarity influence of communications on transportation, although outweighed by a substitutionary

TABLE 4 Summary of Significant Relationships Between Transportation and Communications

	Alt. 1		Alt. 2		Alt. 3		Alt. 4		Alt. 5		Alt. 6	
Price → Demand	Without t	With t	Without t	With t	Without t	With t	Without t	With t	Without t	With t	Without t	With t
Transportation → communications	S^{IH}											
PV cap → old tech												$S^{IM,IH}$
PV op → old tech							$S^{WM,WH}$	S^{WH}				
Non-PV → old tech			$C^{IM,IH}$		$C^{IM,IH}$							
Lodging/PT → old tech							$C^{IM,IH}$		$C^{IM,IH}$			
Public trans. → old tech											$C^{IM,IH}$	$C^{IM,IH}$
Entertainment → old tech							$S^{IM,IH,WM,WH}$	$S^{WM,WH}$				
Non-PV → new tech			$S^{IM,IH}$		$S^{IM,IH}$							
Lodging/PT → new tech									$S^{IM,IH}$			
Public trans. → new tech											$S^{IM,IH}$	
Entertainment → new tech							$C^{IM,IH,WM,WH}$					
Communications → transportation		$C^{WM,WH}$										
Old tech → PV cap							$C^{WM,WH}$				S^{IH}	
Old tech → PV op					$C^{IM,IH,WM,WH}$	$C^{IM,IH,WM,WH}$	$C^{IM,IH,WM,WH}$	$C^{IM,WM, WH}$	$C^{IM,IH,WM,WH}$	$C^{IM,IH,WM,WH}$	$C^{IM,IH,WM,WH}$	$C^{IM,IH,WM,WH}$
Old tech → non-PV				$S^{WM,WH}$		$S^{WM,WH}$						
Old tech → lodging/PT									$S^{WM,WH}$	$S^{WM,WH}$		
New tech → PV			C^{IM}	C^{WM}								
New tech → PV cap					C^{IM}	$C^{WM,WH}$	$C^{WM,WH}$	$C^{WM,WH}$	C^{IM}	$C^{WM,WH}$	$C^{IM,IH}$	$C^{WM,WH}$
New tech → PV op							C^{WM}	S^{IH}, $C^{WM,WH}$				
New tech → lodging/PT							$C^{WM,WH}$					

S = substitution, C = complementarity, IM = Marshallian (uncompensated) elasticity in the individual CPI model, IH = Hicksian (compensated) elasticity in the individual CPI model, WM = Marshallian (uncompensated) elasticity in the weighted CPI model, WH = Hicksian (compensated) elasticity in the weighted CPI model.

TABLE 5 Comparison of This Study and Related Aggregate Analyses

	Selvanathan and Selvanathan (*13*)	Lee and Mokhtarian (*8–10*; unpublished data, 2005)	Present Study
Methodology	Consumer demand model (Rotterdam)	Input–output analysis of industrial demand	Consumer demand model (LA/AIDS)
Study period	1960–1986	1947–1997	1984–2002
Study area	Australia, United Kingdom	United States	United States
Key findings	Public transportation (PuT), private transportation (PrT), and communication (C) are pairwise substitutes. Influence of PrT on C is much stronger (price elasticities of 0.57 for United Kingdom and 0.31 for Australia) than influence of C on PrT (0.08 and 0.04, respectively). True to a lesser degree for the influence of PuT on C (0.09 and 0.18) compared to the converse (0.03 and 0.07).	For 10 benchmark years in the study period, analyzed correlations of total industrial demand for transportation manufacturing (TM) and utilities (TU), and communication manufacturing (CM) and utilities (CU), as well as transportation (T) and communications (C) overall. TM and CM are complements. TU and CM are substitutes through 1967 and complements thereafter. TM and CU; TU and CU; and T and C are substitutes through 1982 and complements thereafter.	Personal vehicle (PV) and public transportation (PT) are substitutes where relationship is significant. Influence of T on C is most often (20 out of 36 significant relationships) substitution. Influence of C on T is significant more often (66 times) than the converse, and is most often (56 times) complementarity.

NOTE: Consumer perspective, Australia, United Kingdom versus United States (present study), nearly disjoint study periods. United States, study period overlap (1984–1997), industry (Lee and Mokhtarian) versus consumer perspective (present study).

influence, did exist. Thus, although one cannot be sure, this suggests that perhaps similar complex processes are at work in both cases—weighted differently for the earlier study, but perhaps more similar if Selvanathan and Selvanathan were to be replicated in Australia and the United Kingdom in a time frame similar to that of this study.

Turning now to the two U.S. studies in the lower part of Table 5, the comparison is not as straightforward because different categorizations and approaches were used. What is interesting, however, is that although some substitution effects appear for the U.S. industrial demand studies of Lee and Mokhtarian, those effects disappear completely after 1982: for the 1987, 1992, and 1997 benchmark years, every correlation between a measure of transportation and one of communications is positive (although several are not statistically significant), indicating complementarity. Because 1986 is the last year covered by Selvanathan and Selvanathan, there is again a hint that earlier relationships were undergoing a qualitative shift in that general time frame—clearly switching from substitution to complementarity in the case of industrial demands in the United States and perhaps doing something similar in the case of consumer expenditures in all three countries studied.

In sum, this study has added to understanding the nature of the association between communications and travel, with respect to their roles in the consumer sector of the economy. The existence of effects in both directions (substitution and complementarity) is testimony to the complexity of the relationships involved, with both generation and replacement possible and happening simultaneously. Despite this complexity, however, one result is quite clear: there is very little empirical support for the expectation that new communications technologies will substitute for PV travel (although there is evidence of substitution for non-PV travel, specifically the PT category, which includes airline travel as well as urban mass transit). On the contrary, there is considerable support for a complementary impact of new technologies on both PV and non-PV travel. Thus, the outcome of this study will be of interest to policy makers and planners who are considering, or may consider, telecommunications in the broad sense as a transportation demand management policy tool.

ACKNOWLEDGMENTS

This research was funded by the University of California Transportation Center. Comments by the referees have improved this paper.

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The Telecommunications and Travel Behavior Committee sponsored publication of this paper.