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Relationships between US consumer expenditures on communications and transportation using almost ideal demand system modeling: 1984-2002

### Permalink

<https://escholarship.org/uc/item/8b32t1gg>

### Journal

Transportation Planning and Technology, 30(5)

### ISSN

0308-1060

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### Publication Date

2007-10-01

Peer reviewed

**RELATIONSHIPS BETWEEN U.S. CONSUMER EXPENDITURES ON  
COMMUNICATIONS AND TRANSPORTATION USING ALMOST IDEAL DEMAND  
SYSTEM MODELING: 1984–2002**

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August 2007

*Transportation Technology and Policy* **30(5)**, 2007, pp. 431-453

## **ABSTRACT**

This study analyzed aggregate consumer expenditure data from the U.S. for the 19 years 1984–2002, to determine the relationships between expenditures on transportation and those on communications. We first identified 15 categories of goods – nine for transportation, five for communications, and one for all others – and obtained prices for each category across time by using the Consumer Price Index (as is common practice). Then, we applied the linear approximate Almost Ideal Demand System method for estimating consumer demand functions, aggregating the categories to six (non-personal vehicle, personal vehicle capital, personal vehicle operation, electronic communications media, print communications media, and all others) due to the small sample size. The results indicate that transportation and communications categories have both substitution and complementarity relationships. For example, price increases for non-personal vehicle (non-PV) travel increase electronic media spending, indicating a substitution relationship, while electronic media price changes have a complementary effect on PV capital expenditures. 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. In addition, expenditures in the transportation categories are generally more income-elastic and price-elastic than those in communications, indicating that communications expenditures are more essential than those for travel. The transportation categories have both substitution (PV capital and non-PV categories) and complementarity (non-PV and PV operation categories) relationships with each other, while the two communications categories have a substitution relationship.

**Keywords:** Consumer Expenditure Survey, consumer demand system, Almost Ideal Demand System (AIDS), telecommunications – transportation, ICT – transportation, substitution versus complementarity

## 1. INTRODUCTION

The relationship between telecommunications and travel has been a fertile area of research for several years. Early speculation (e.g., Owen, 1962) focused on the potential of telecommunications to replace travel. That hope eventually led to the establishment of several telecommuting programs, and empirical evaluations of those programs (e.g., Hamer, *et al.*, 1991; Mokhtarian, *et al.*, 1995) seemed to support the substitution expectation. While empirical evidence for other telecommunications applications was far more scarce, it was similarly expected that teleconferencing, teleshopping, distance learning, and other such services would also replace travel. In the meantime, however, some scholars (e.g. Albertson, 1977; Salomon, 1985; Mokhtarian, 1990, 2003; Niles, 1994) began to point out that substitution was not the only possible impact of telecommunications on transportation. In particular, it was argued that a very likely impact would be the generation of more travel, or complementarity. In the short term, this effect could arise in two kinds of ways, which the literature (Salomon, 1986) labels *enhancement* and *efficiency*.

- *Enhancement* refers to a direct impact of one mode of communications (e.g. telecommunications) on the *demand* for another mode (e.g. travel). For example, the increasing ease of electronically obtaining information about interesting locations, activities, and people could stimulate the demand for travel to visit those locations or people and engage in those activities (Gottman, 1983; Couclelis, 1999).
- *Efficiency* refers to the use of one mode (e.g. telecommunications) to improve the operation of another mode (e.g. the transportation network). The effect on demand is indirect in this case, by increasing the effective *supply* of transportation and hence, by lowering its (generalized) cost, making travel more attractive and thus increasing the demand for it.

Based partly on the favorable empirical results mentioned above, and partly on the optimism and opportunism endemic to public sector decision-making, a number of public policies have been promulgated on the assumption that telecommunications will be a useful trip reduction instrument (e.g., Gordon, 1992, 1996; Castaneda, 1999; Joice, 2000). However, Mokhtarian and Meenakshisundaram (1999) suggest that the empirical findings in support of substitution may be a conse-

quence of the short-term, disaggregate, narrow focus of the typical telecommuting (or other application) evaluation, and that when the focus is broadened to examine all communications across the entire population over a period of time, it is more likely that a complementarity effect will emerge. Certainly, any plot of the aggregate amounts of communications and travel over time, at practically any geographic level (e.g. Grubler, 1989), illustrates that overall, they continue to rise together.

Given the favor with which telecommunications is viewed as a transportation demand management tool, it is important to better understand the nature of its relationship with travel, in order to determine whether the optimism about its substitution potential is misplaced. In particular, it seems vital to move beyond the small-scale evaluations of single applications such as telecommuting, to a more complete view of telecommunications activity in general. Such studies could be conducted at either the disaggregate or the aggregate level, and each approach has its advantages (Mokhtarian and Salomon, 2002): disaggregate studies have the potential to offer more insight into behavior-based causal relationships, whereas aggregate studies can offer a more comprehensive scope and the potential for more readily developing aggregate forecasts of the impacts of telecommunications on travel (and conversely).

The few aggregate studies that have been conducted to date on this question appear to offer contradictory results. An input-output (I-O) analysis of relationships between transportation and communication input intensities across 44 *industry* classes in Europe in 1980 found strong evidence of *complementarity* (Plaut, 1997), while a simultaneous equation (Rotterdam) demand model of aggregate *consumer* expenditures in Australia and the UK in 1960-1986 found that private transportation, public transportation, and communication are pairwise *substitutes* (Selvanathan and Selvanathan, 1994). The latter study further found exponential growth in communication, at the expense of the two types of transportation. Similar results have also been put forward by NOASR (1989), suggesting relatively low elasticities and a reduction of travel by only 8% over the next 35 years. On the other hand, Choo and Mokhtarian (2005) found that the aggregate relationship between actual amounts of travel (including vehicle-miles traveled, transit passengers carried, and domestic airline passenger-miles traveled) and telecommunications (including telephone calls and mobile phone subscribers) is complementarity, using structural equation modeling for national time series data (1950-2000) in the U.S. (reflecting both business and personal activity).

In fact, all these results are plausible. The consumer-oriented finding of net substitution is consistent with the nearly unanimous empirical results of numerous micro-scale studies, whereas the findings of complementarity are consistent with historically-observed simultaneous increases in both transportation and communication in the aggregate (Mokhtarian, 2003). The divergent findings are not only empirically substantiated by these other studies, but are also conceptually reasonable (Plaut, 1997). As indicated earlier, complementarity can arise both through an enhancement effect (in which use of one mode of communication directly stimulates use of other modes) and through an efficiency effect (in which use of one mode in conjunction with another improves the efficiency of the latter). It is quite possible that both effects are obtained more strongly in an industrial context than in a consumer one. For example, the expansion of personal contacts through electronic means is more likely to lead to increased travel (enhancement) in a business context than in a social one. The use of electronic data interchange and global positioning systems (efficiency) have benefited goods movement more than, say, automobile drivers.

On the other hand, that balance may begin to shift as enhancing and efficiency-improving technologies such as mobile phones, the Internet, and in-vehicle navigation systems permeate the consumer sector more deeply. Hence, it is possible that, over time, the net substitution effect previously seen for consumer demand may weaken and even reverse into a complementarity effect. The latest year in the time-series data used by Selvanathan and Selvanathan was 1986; a shift may already be detectable in the intervening two decades. Thus, it is highly desirable to update and refine the Selvanathan and Selvanathan work.

The purpose of this study is to do precisely that. Specifically, we analyze aggregate consumer expenditure data from the U.S. for the 19 years 1984–2002, using aggregate demand system modeling (in particular, a linear approximate almost ideal demand system model), to determine the relationships between expenditures on transportation and those on communications.

The organization of the paper is as follows. The next section describes the methodology for aggregate consumer demand modeling. Section 3 presents U.S. consumer expenditure and price data on communications and travel. Then, we describe their trends in Section 4. Section 5 analyzes the model results for the demand system, focusing on the expenditure and price elasticities. Finally, conclusions are discussed.

## 2. METHODOLOGY

A number of methods have been developed and applied for estimating aggregate consumer demand functions, including the Rotterdam (Theil, 1976), translog (Christensen, *et al.*, 1975), and Almost Ideal Demand System (AIDS, Deaton and Muellbauer, 1980) approaches. Among them, this study employs the AIDS method since it is more flexible and has many desirable properties of a demand system such as homogeneity and symmetry. The general form of the AIDS model can be written as

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

where  $w_i = \frac{p_i q_i}{\sum_j p_j q_j}$  is the expenditure share of good  $i$ ,  $p_j$  is the price of good  $j$ ,  $X$  is the total

expenditure on all goods (often treated as synonymous with income),  $\alpha_i$  is the constant coefficient in the  $i^{\text{th}}$  share equation,  $\gamma_{ij}$  is the slope coefficient associated with the price of good  $j$  in the  $i^{\text{th}}$  share equation,  $\beta_i$  is the slope coefficient associated with the total expenditure in the  $i^{\text{th}}$  share equation, and  $P$  is a price index defined as

$$\ln P = \alpha_0 + \sum_j \alpha_j \ln p_j + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln p_i \ln p_j, \quad i, j = 1, 2, \dots, k.$$

According to consumer (price) theory, the following restrictions should hold, although they have often been found to fail in practice:

- (i)  $\sum_i \alpha_i = 1, \sum_i \gamma_{ij} = 0, \sum_i \beta_i = 0$  (adding up);
- (ii)  $\sum_j \gamma_{ij} = 0$  (homogeneity); and
- (iii)  $\gamma_{ij} = \gamma_{ji}$  (symmetry).

Adding up means that the total budget is spent on  $k$  different goods (ensuring that the shares sum to 1), indicating the budget constraint  $X = \sum_i p_i q_i$ , where  $q_i$  is the quantity demanded of good  $i$ .

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 both income and prices 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, the unconstrained system can be estimated, and then statistically tested as to whether the homogeneity and symmetry restrictions are empirically justified. Alternatively, the homogeneity and symmetry conditions can simply be imposed on the model at the outset. Also, the adding up (across equations) restrictions are generally imposed by deleting any one of the equations in estimation and imputing its coefficients from the adding up restrictions.

In empirical studies, however, it is common to use Stone's price index ( $P^*$ ) instead of  $P$  since the inclusion of  $\ln P$  makes the equation for  $w_i$  highly non-linear in the unknown  $\alpha$  and  $\gamma$  coefficients. Stone's price index can be denoted as

$$\ln P^* = \sum_j w_j \ln p_j, \quad j = 1, 2, \dots, k.$$

That is, the composite log-price of goods is the weighted average of log-prices across all goods (categories), where the weights are the shares of expenditures on each good (category). The AIDS model using Stone's index is called the linear approximate AIDS (LA/AIDS) model (Blanciforti and Green, 1983). The LA/AIDS model is theoretically and practically reasonable, and easily interpretable (Alston and Chalfant, 1993; Lazaridis, 2003).

In the LA/AIDS model, noting that  $w_i = \frac{p_i q_i}{X}$  is a function of  $X$  and using the product rule of differentiation, the *income (expenditure) elasticity* of demand can be calculated as (see also Buse, 1994; Green and Alston, 1990):

$$e_{income} = \frac{\partial q_i}{\partial X} * \frac{X}{q_i} = \frac{\partial(w_i X)}{\partial X} * \frac{X}{p_i q_i} = (\beta_i / w_i) + 1,$$

where  $p_i$  and  $q_i$  are the price and quantity demanded of good  $i$ , respectively.

There are two types of *price elasticities* of demand (the percentage change in quantity demanded of good  $i$  ( $q_i$ ) given a percentage change in the price of good  $j$  ( $p_j$ )), Marshallian



(uncompensated) and Hicksian (compensated):

- Marshallian (uncompensated) elasticity

$$e_{ij}^M = \frac{\partial q_i}{\partial p_j} * \frac{p_j}{q_i} = -\delta_{ij} + (\gamma_{ij} / w_i) - \beta_i (w_j / w_i),$$

- Hicksian (compensated) elasticity

$$e_{ij}^H = e_{ij}^M + w_j e_{income} = -\delta_{ij} + (\gamma_{ij} / w_i) + w_j,$$

where  $\delta_{ij}$  is the Kronecker delta ( $\delta_{ij} = 1$  if  $i = j$ ; and 0 otherwise). The Marshallian elasticity is based on maximizing utility under the budget constraint, while the Hicksian elasticity is based on minimizing expenditures at a fixed utility level (Nicholson, 1992). The former comprises both substitution and income effects, whereas the latter includes the substitution effect only. They are identical except for the  $w_j(\beta_i/w_i + 1)$  term in the Hicksian elasticity, which is  $w_j$  times the income elasticity of demand for good  $i$ . This means that when Marshallian price elasticities are negative (as would generally be the case, for example, for own-price elasticities) and income elasticities are positive (as is true for normal goods), the compensated elasticity is less negative (less price elastic) than the uncompensated one. Since the three elasticities in the model are functions of the parameters being estimated ( $\beta$ s and  $\gamma$ s), t-tests on their values can be conducted using the estimated variances and covariances of the parameter estimators (Blanciforti and Green, 1983). As usual, the null hypothesis is that an elasticity is equal to zero, meaning that demand is not related to price or income changes.

In this study, we employ the LA/AIDS approach, estimate unconstrained models, and then test the homogeneity and symmetry restrictions. Consumer price index data are used to develop prices for aggregate item categories. Additionally, the expenditure and both types of price elasticities are calculated and compared.

### 3. ASSEMBLING THE CONSUMER EXPENDITURE AND PRICE DATA

This section describes the available consumer expenditure data and consumer price index (CPI) data, with particular attention to the transportation and communications categories analyzed in this study. The data for this study ranges from 1984 to 2002 (19 years) due to compatibility and availability issues for years outside that range.

### 3.1 Consumer Expenditure Data

Consumer expenditure surveys (CES) are conducted to collect data on expenditures for goods and services that are used in consumers' daily lives. The Bureau of Labor Statistics (BLS) performs consumer expenditure surveys, and also collects some information such as the amount and sources of family income, changes in savings and debt, and demographic and economic characteristics of the consumer unit<sup>1</sup>. The survey actually comprises two individual sets of instruments: the interview survey and the diary survey. For the interview survey, approximately 15,000 addresses are contacted in each quarter of the calendar year. The interview survey uses a rotating panel sample, so that one-fifth of the addresses contacted each quarter are newly recruited to the survey. Among the 15,000 addresses, usable interviews are obtained from approximately 7,600 households each quarter, so that the total number of interviews for the year is about 30,400. For the diary survey, a sample of about 12,500 addresses is selected each year, which nets usable diaries from approximately 7,700 households. Each consumer unit completes two separate questionnaires (i.e. a Household Characteristics Questionnaire and a Record of Daily Expenses diary<sup>2</sup>) per sample, so the total number of surveys per year is approximately 15,400.

To identify the items analyzed in this study, we started with the two broadest conceptual categories of transportation and communications, and then split them into smaller groups following the categorization structure available in the data. Finally, we identified nine items closely related to transportation, and five items associated with communications. Brief explanations<sup>3</sup> of each item category are presented below. 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

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<sup>1</sup> A consumer unit (CU) comprises all members of a particular housing unit who are “related by blood, marriage, adoption, or some other legal arrangements”, or who are unrelated but financially dependent on each other for major living costs (U.S. DOL, 2004).

<sup>2</sup> In the Household Characteristics Questionnaire, the interviewer records socioeconomic information such as the age, gender, race, marital status, family composition, work experience, and incomes of each member of the consumer unit. In the Daily Expenses Record, respondents record detailed information on all expenses for two consecutive weeks.

<sup>3</sup> The explanations of the 14 categories are excerpted from the “Glossary” that is available on the BLS website ([www.bls.gov/cex/csxgloss.htm](http://www.bls.gov/cex/csxgloss.htm)).

lodging” category is identified as a transportation item in our 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 since it contains 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 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.
- *Public Transportation*: Fares for mass transit, buses, trains, airlines, taxis, school buses for which a fee is charged, and boats.
- *Vehicle Purchases: Cars and Trucks, New*: The purchase of new domestic and imported cars and trucks and other vehicles, including motorcycles and private planes.
- *Vehicle Purchases: Cars and Trucks, Used*: The purchase of used domestic and imported cars and trucks and other vehicles, including motorcycles and private planes.
- *Vehicle Finance Charges*: The 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 auto repair policies.

- *Vehicle Insurance*: The premium paid for insuring cars, trucks, and other vehicles.

### *Communications*

- *Telephone Service*: All charges related to telephone calls (telephone equipment falls under the category below).
- *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 kinds of postage and stationery supplies.
- *Reading*: Subscriptions for newspapers and magazines; books through book clubs; and the purchase of single-copy newspapers, magazines, newsletters, books, and encyclopedias and other reference books.

## **3.2 Consumer Price Index Data**

The consumer price index (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 the BLS’s trained representatives. The U.S. Census Bureau conducts the Telephone Point-of-Purchase Survey (TPOPS) to acquire data on retail outlet prices, and demographic and socio-economic

information from consumer units. Prices are collected in 87 urban areas from about 50,000 housing units and nearly 23,000 retail outlets such as department stores, supermarkets, and hospitals. Basic CPIs are first calculated for each of 8018 item-area combinations, and then aggregate CPIs are calculated by weight-averaging subsets of the total combinations. The weights for the aggregate CPIs are based on reported expenditures from the surveys. Then, BLS publishes CPI data for all urban consumers (CPI-U) and for urban wage earners and clerical workers (CPI-W) every month. The CPI-U measures the price changes obtained from samples representing nearly all residents of urban or metropolitan areas, consisting of about 87% of the U.S. population in 1990. Not included in the population of this CPI are people living in non-metropolitan areas, in the Armed Forces, and farm families. On the other hand, the CPI-W is calculated based on a subset of the CPI-U population, consisting of about 32% of the U.S. population in 1990. The CPI-W's population consists of households for which most (50% or more) of their income comprises wages and clerical workers' earnings. The CPI-U measures are used for this study, as being most closely congruent to the population represented by the national CES data.

We selected CPI categories associated with transportation and communications, considering the consumer expenditure categories discussed above. CPIs for most categories are available for the study period (1984-2002). 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. We used the relative importance<sup>4</sup> (hereafter "weight") of each category in the CPIs 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). 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.

Since the published categories for consumer expenditures and the consumer price index are not exactly the same, we need to reconcile them. In this study, we focus more on consumer expenditures (as measures of consumer demand) than on the consumer price index, so CPI

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<sup>4</sup> For example, the weight of CPI for food is 16.19. That is, the price of all food items constitutes 16.19% of the price of all items.

categories should be combined based on the consumer expenditure categories (nine transportation and five communications). Composite CPIs are required not only for the four categories noted in Table 1 (and in fact, the 14 categories of that table are not modeled directly, due to the small sample size of our data set), but also when groups of the 14 categories are combined. The weights of items comprising a CPI are used for creating composite CPIs. For additional details on these and other aspects of the study, see Choo, *et al.* (2006).

[Table 1 goes about here]

#### **4. CONSUMER EXPENDITURE TRENDS**

This section describes trends with respect to consumers' expenditure patterns in transportation and communications categories from 1984 to 2002. Figure 1 shows the nine transportation and five communications expenditure trends, including their shares. Current-dollar expenditures in all 14 categories are increasing over time although several categories (e.g. Veh\_New (new vehicle purchases), Oth\_Lodg (out-of-town lodging), and Reading) tend to be relatively erratic. Among the transportation categories, Veh\_Used (used vehicle purchases) shows the largest rate of increase (\$64/year, on average). The Veh\_New (new vehicle purchases) and Veh\_Insur (vehicle insurance) categories also show relatively high rates of increase (\$27/year each), indicating that private vehicle related expenditures increased faster than those for public transportation (\$11/year), out-of-town lodging (\$5/year), or other entertainment (Oth\_Enter, \$12/year). Among the communications categories, Telephone (telephone service) and Misc\_HH (miscellaneous household equipment, including computer software and hardware) show relatively high rates of increase (\$29 and \$27/year, respectively) and TV\_Radio shows a moderate increase of \$18/year, while Postage and Reading show increases of only \$2/year and \$0.54/year, respectively. These results are consistent with expectations, in view of the dramatic advances in telephone and computer-related technology in recent years.

[Figure 1 goes about here]

Of course the current-dollar trends reflect the effects of inflation as well as true changes

in spending patterns. Expressing expenditures in terms of shares largely controls for inflation<sup>5</sup>. As shown in Figure 1, the expenditure share trends for the 14 categories are quite different from the expenditures in dollar terms. In terms of share, eight out of the 14 categories are actually decreasing over time from 1984 to 2002: out-of-town lodging, new vehicle purchase, gasoline, vehicle finance, vehicle maintenance, public transportation, postage, and reading. Similar to expenditures, Veh\_Used shows the largest increase in share (7.4 percentage points/year, on average). In contrast to the steady increase in raw expenditures on Reading, its share is gradually decreasing over time, showing a loss of 0.1 percentage points per year. In the opposite direction, Telephone shows an increase in share of about twice the magnitude, gaining more than 0.2 percentage points in share each year.

## 5. DEMAND SYSTEM MODELING

### 5.1 Model Specification

Expenditure share ( $w_i$ ) and price ( $p_i$ ) variables for communications, transportation, and “other” categories are needed to estimate LA/AIDS models. As discussed in Section 3, there are nine subcategories and five subcategories for transportation and communications, respectively. Our data on these variables are available only from 1984 to 2002 (19 years of observations). The expenditure share for the “other” category is calculated by subtracting the sum of the expenditure shares of all transportation and communications categories from unity. Since price and quantity data for all goods are not available, in keeping with common practice CPI data are used for the price variables in the LA/AIDS models (Blanciforti, et al., 1986; Eales and Unnevehr, 1988). Additionally, we created a CPI for the “other” category using its relative importance among the CPIs.

In practical terms, 14 equations (not counting the “other” category) cannot be estimated simultaneously, because our data has only 19 years of observations and the number of parameters to be estimated in an LA/AIDS model would exceed the number of observations. Thus, based on the various conceptual groupings for the 14 communications and transportation

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<sup>5</sup> Choo, *et al.* (2005) present and discuss trends in constant-dollar terms (i.e. correcting raw expenditures for inflation) as well as current-dollar terms. Whereas in current dollars the results for raw expenditures are quite different from the results for shares, in constant dollars the two sets of trends are substantively similar to each other, and to the current-dollar share results.

categories, we explored several alternative grouping schemes.

In this paper, we present a five-group alternative scheme, consisting of non-personal vehicle (PV), PV capital, PV operation, electronic communications media, and print communications media (see subcategories in Table 1). The first three groups are related to transportation and the last two are related to communications. This classification is conceptually reasonable and meaningful for exploring relationships between transportation and communications. Choo, *et al.* (2006, forthcoming) present summary results across a variety of alternative grouping schemes.

We estimate an LA/AIDS model for this grouping and calculate expenditure, own-, and cross-price elasticities in the following section. SAS 8.0 is employed for model estimation, using the iterative seemingly unrelated regression estimation (SURE) method. This method also allows users to easily test the homogeneity and symmetry of the models.

## 5.2 Model Results

For model estimation, the equation for the “other” category was deleted in the LA/AIDS model to achieve the adding-up restriction. Although the parameters of the deleted equations can be manually obtained through the adding-up condition, they are not presented here since we focus on relationships between communications and transportation. The parameters of the LA/AIDS model were first estimated, and then expenditure and price elasticities were calculated at mean values of expenditure shares. In view of the small sample size, we adopt the relatively liberal standard of  $p\text{-value} < 0.1$  as the threshold for statistical significance.

We tested the utility and demand theory-based symmetry and homogeneity restrictions using F-tests. The AIDS models rejected the restrictions. In fact, many empirical studies (including the foundational one of Deaton and Muellbauer, 1980) reject both conditions. This may be because the symmetry and homogeneity restrictions are only satisfied in a steady state situation (Durberry, 2002). In view of the fact that our model is based on time series data (which are dynamic), we present the model results obtained without imposing the restrictions, as is often done.

Estimated parameters of the AIDS model appear in Table 2.  $R^2$  values of the equations range from 0.63 to 0.98. More significant coefficients at  $\alpha = 0.1$  are found in the transportation-related equations (11, aside from constants) than in the communications-related equations (3).



As shown in Table 3, all expenditure elasticities are positive, indicating that all categories are normal goods. That is, as total expenditure (income) increases, demand for each category increases. Additionally, all except the one for print communications media are significant. Except for PV operation, the transportation categories have higher elasticities than the communication ones do. That is, as income increases, consumers tend to increase their spending on transportation-related goods and services by a higher proportion than their increase in spending on communication. Additionally, the non-PV and PV capital categories have expenditure elasticities greater than one (indicative of a luxury good), while communication expenditure elasticities are about equal to or less than one (the latter case indicative of a necessary good).

[Tables 2 & 3 go about here]

All own price elasticities (shaded cells) are either negatively significant (meaning that an increase in price decreases the quantity purchased) or insignificant. Especially, the non-PV category has the highest elasticity, and among the significant ones, the PV operation category has the second-highest. Expenditures in the non-PV category are own-price elastic, consistent with other evidence that domestic air travel demand is price elastic (Gillen, *et al.*, 2004). Spending in the PV operation category is inelastic, less than one in absolute magnitude, indicating the essential nature of vehicle operating costs. The PV capital category has a positive sign (and is relatively large at 0.25 Marshallian and 0.50 Hicksian, although not significant in either case), which is counter-intuitive. However, it may be interpreted that cars are such a necessity that even when their price increases, consumers continue to purchase them. As expected, Marshallian own-price elasticities are slightly larger (i.e., more price elastic) in absolute value than Hicksian own-price elasticities since the former elasticities consider both substitution and income effects. In view of the equations presented in Section 2, mathematically, this will be true whenever the Marshallian own-price elasticity is negative and the income elasticity,  $\beta_i/w_i + I$ , is positive.

Turning to the cross-price elasticities within category, the PV capital and non-PV transportation groups have a substitution relationship (of a similar magnitude in both directions, although significant only for the impact of a change in PV capital prices on expenditures for non-PV items, which include transit, air fares, and out-of-town lodging). This substitution

relationship indicates an expected mode shift impact of price changes among transportation modes. On the other hand, it is also logical that the non-PV and PV operation categories have a complementary relationship. These two categories are directly related to auto travel. Non-PV goods and services are often accompanied by PV travel (to access the lodging, the transit, or the airport), so that a rise in price of those items, leading to a cutback in their demand, would cut the demand for operating a PV as well. Their cross-price elasticities (where significant) are less than one, indicating an inelastic relationship.

Similarly, within communications, the relationship between electronic and print communications media categories is substitution. As the prices of telephone and the Internet decline relative to those for postage and print media, consumers are likely to replace some mail and print purchases with electronic counterparts. The cross-price elasticities of the electronic communications media category on print communications media spending are significant and greater than one.

Turning to cross relationships between communications and transportation, we find both substitution (one) and complementarity (three) effects between the two. The non-PV and electronic communications media categories are substitutes. That is, consumers tend to increase their expenditures on electronic communications media when non-PV costs increase (although disproportionately less than the cost increase), suggesting substitution effects such as video (or audio) conferencing in lieu of business travel, or replacing a transit commute with telecommuting, or shifting time and money formerly spent on recreational travel to electronic entertainment.

On the other hand, the impact of print communications media on PV operation is complementarity, with elasticities greater than one. This suggests that the increased consumption of old-fashioned communications such as mail, magazines, and books that accompanies a price decrease (indicative of a wider-than-average range of interests, activities, and personal relationships), leads to increased personal vehicle use (i.e. that increased travel is one natural outcome of that broader range). A similar complementary relationship appears to operate in the reverse, between the non-PV and print communications media categories, meaning that consumers tend to increase their expenditures on print communications media when non-PV costs decrease and hence its demand increases. In broad terms, this is suggestive of a bidirectional feedback loop between travel and print communications, with increased consum-

ption of print media both generated by, and generating, increased travel. In addition, the electronic communications media and PV capital categories have a strong complementarity relationship (showing -1.89 and -1.74 for Marshallian and Hicksian elasticities, respectively). That is, when electronic communications media costs decrease, consumers tend to increase their expenditures on purchasing cars (disproportionately greater than the cost decrease).

## 6. CONCLUSIONS

This study analyzed aggregate U.S. consumer expenditure data for the 19 years from 1984 to 2002, to determine the relationships between expenditures on transportation and those on communications. Specifically, we applied the LA/AIDS method for estimating consumer demand functions. This approach is standard in economics for modeling the share of a household's expenditures on each category of goods, as a function of the prices of all categories of goods, as well as income (operationalized as total expenditures). We first identified 15 categories of goods – nine for transportation, five for communications, and one for all others – and obtained prices for each category across time by using the Consumer Price Index (as is common practice). Then, we estimated an LA/AIDS model based on aggregating the categories to five (non-personal vehicle, personal vehicle capital, personal vehicle operation, electronic communications media, and print communications media) due to the small sample size (19 years).

The results indicate that transportation and communications categories have both substitution and complementarity relationships. 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. Specifically, the effect of non-PV travel (including out-of-town lodging, recreational vehicles, public transit, and airline travel) on electronic communications media is substitution. This suggests that non-PV travel (including long-distance (air) travel) is more likely than PV travel to be replaced with electronic communications. This result is consistent with that of Selvanathan and Selvanathan (1994), although their analysis is based on a more aggregate level of classification (public and private transportation and communications). On the other hand, the effects of (1) non-PV travel on print communications media, (2) print media on PV operations, and (3) electronic media on PV capital spending are complementarity, pointing to synergistic relationships among various

forms of communication (including “old media”) and travel. In view of the conceptual and empirical evidence for both substitution and complementarity effects, we cannot rule out the possibility that even some of the statistically-insignificant elasticities actually represent the net outcome of roughly equal effects in both directions. Overall, however, the dominant effect appears to be complementarity, consistent with Choo and Mokhtarian (2005): as telecommunications demand increases, travel demand increases.

Furthermore, it is also found that transportation categories are generally more income-elastic and price-elastic than communications ones, indicating that communications expenditures are more essential than travel. The transportation categories have both substitution (PV capital and non-PV categories) and complementarity (PV operation and non-PV) relationships, while the two communications categories have a substitution relationship.

This study has a limitation in refining the expenditure categories of transportation and communications due to data availability. Although a few expenditure categories include some items other than transportation and communications, their impacts on the model interpretation are likely to be minor since their expenditure proportions of the associated categories seem to be small.

Overall, this study has added to our understanding of the nature of the association between communications and travel at the aggregate level, with respect to their roles in the consumer sector of the economy. Our analysis relied on data from the United States, but we suspect our results to be generalizable to other Western economies – although of course it would be desirable to confirm or refute that supposition through the analysis of other countries’ comparable datasets. In any case, our results provide further evidence that although the relationship between the two is complex, there is no empirical support for the expectation that electronic communications media will substitute for personal vehicle travel on net (although there is evidence of substitution for non-personal-vehicle travel, specifically the public transportation category which includes airline travel as well as urban mass transit). Thus, these findings should be of interest to policymakers and planners who are considering, or may consider, communications in the broad sense as a transportation demand management policy tool. Additionally, the result implies that communications should be considered as a key factor affecting travel demand (measured by personal vehicle stocks and operation), and vice versa.

## ACKNOWLEDGEMENTS

This research was funded by the University of California Transportation Center.

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**Table 1: Correspondence between Consumer Expenditure and Consumer Price Index Categories**

<b>Consumer Expenditure</b>	<b>Consumer Price Index</b>
<b><i>Transportation</i></b>	
<b><i>Non-personal vehicle</i></b>	
Out-of-town lodging	Combined CPI of housing at school, excluding board, and other lodging away from home including hotels and motels
Public transportation	Public transportation
Other entertainment supplies, equipment, and services	Sporting goods
<b><i>Personal vehicle (capital)</i></b>	
Vehicle purchases: cars and trucks, new	New vehicles
Vehicle purchases: cars and trucks, used	Used cars and trucks
Vehicle finance charges	Automobile finance charges
<b><i>Personal vehicle (operation)</i></b>	
Gasoline and motor oil	Motor fuel
Vehicle maintenance and repairs	Combined CPI of motor vehicle maintenance and repair and motor vehicle parts and equipment
Vehicle insurance	Motor vehicle insurance
<b><i>Communications</i></b>	
<b><i>Electronic media</i></b>	
Telephone	Combined CPI of land-line telephone services, local charges, intrastate toll calls, and interstate toll calls (but not wireless 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
<b><i>Print media</i></b>	
Postage and stationery	Postage (but not delivery services)
Reading	Recreational reading materials

**Table 2: Estimated Parameters of the LA/AIDS Model**

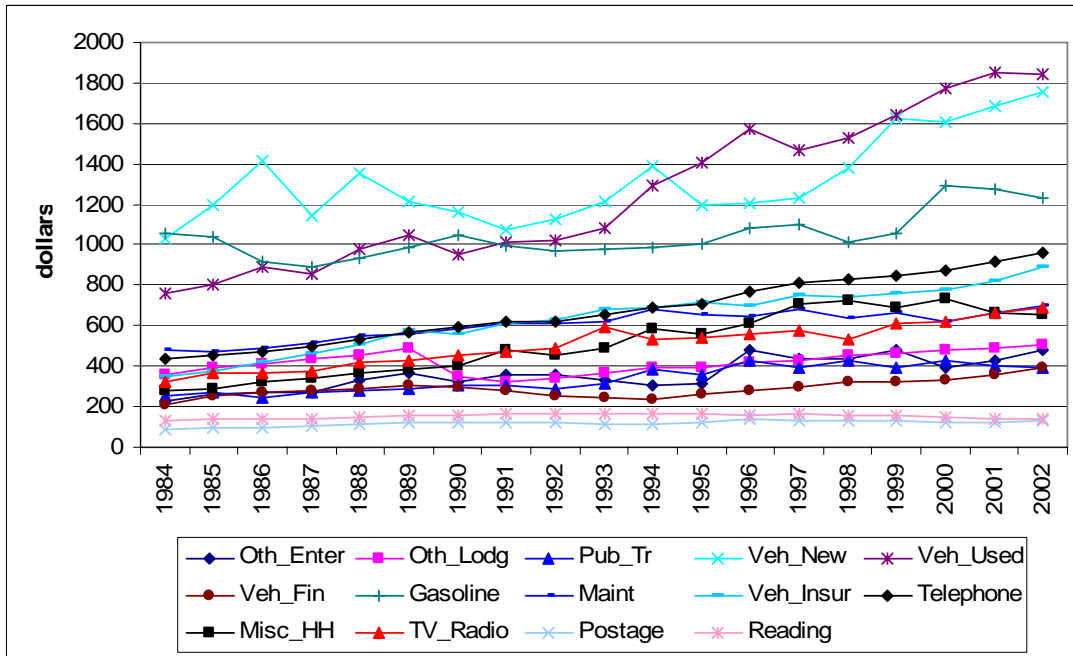
Category	R <sup>2</sup>	Parameter							
		$\alpha_i$	$\gamma_{i1}$ (non-PV)	$\gamma_{i2}$ (PV-capital)	$\gamma_{i3}$ (PV-op)	$\gamma_{i4}$ (elec-tronic)	$\gamma_{i5}$ (print)	$\gamma_{i6}$ (others)	$\beta_i$
Transportation (non-PV)	0.81	-0.359*	-0.00546	0.0601**	0.0514	0.0133	0.0430	-0.213**	0.0743**
Transportation (PV-capital)	0.63	0.0894	0.121	0.130	0.00526	-0.165*	0.0988	-0.484*	0.160*
Transportation (PV-op)	0.98	0.163	-0.02776*	0.000468	0.0394**	0.015262	-0.0916**	0.0954**	-0.0263**
Communications (electronic)	0.96	-0.110	0.0267	0.0155	0.0152	0.0292	-0.0134	-0.0291	-0.00545
Communications (print)	0.96	-0.00171	-0.0135**	-0.00051	-0.00472	0.0116**	0.00570	0.0165	-0.00678*

Notes: \* 0.05 < p-value < 0.1, \*\* p-value ≤ 0.05. Heavily-bordered blocks denote relationships among goods in the same aggregate category of transportation or communications.

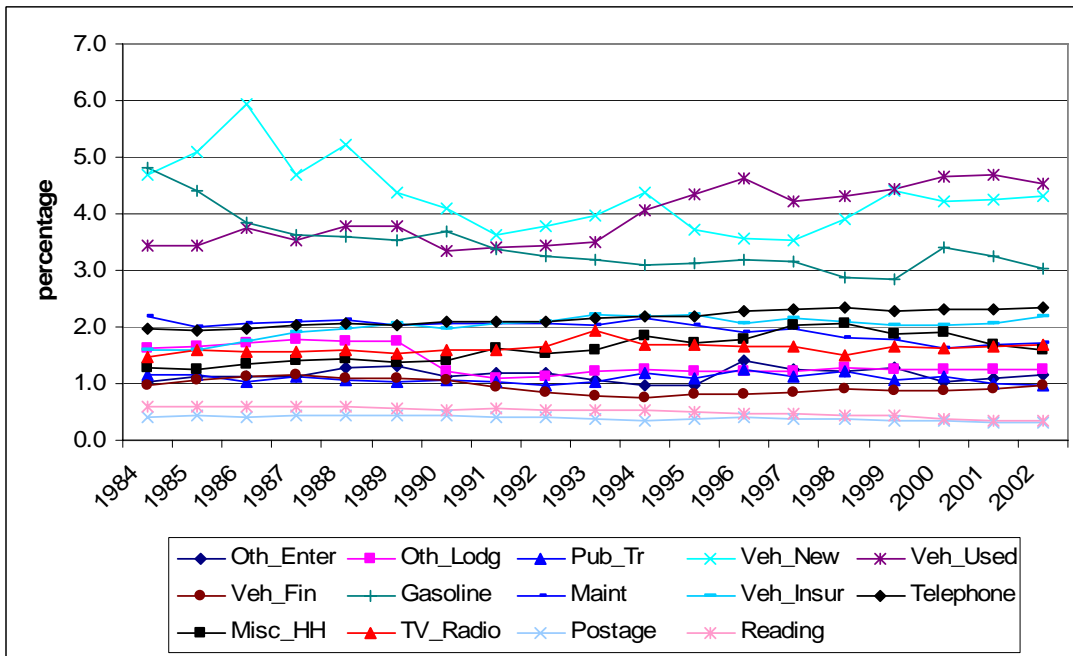
**Table 3: Estimated Expenditure and Price Elasticities**

Category	Expenditure elasticity	Price elasticity									
		Marshallian (uncompensated)					Hicksian (compensated)				
		Non-PV	PV-capital	PV-op	Electronic	Print	Non-PV	PV-capital	PV-op	Electronic	Print
Transportation (non-PV)	3.048**	-1.225*	1.468**	1.265	0.257	1.168	-1.114	1.748**	1.491	0.422	1.196
Transportation (PV-capital)	2.740**	1.247	0.251	-0.072	-1.886*	1.058	1.346	0.503	0.131	-1.738	1.082
Transportation (PV-op)	0.646**	-0.361*	0.039	-0.442*	0.225	-1.231**	-0.338*	0.098	-0.394	0.260	-1.225**
Communications (electronic)	0.899**	0.497*	0.296	0.288	-0.455	-0.247	0.530*	0.379	0.355	-0.406	-0.238
Communications (print)	0.240	-1.486**	0.013	-0.473	1.342**	-0.354	-1.478**	0.035	-0.455	1.355**	-0.352

Notes: \* 0.05 < p-value < 0.1, \*\* p-value ≤ 0.05. Heavily-bordered blocks denote relationships among goods in the same aggregate category of transportation or communications. Shaded cells indicate own-price elasticities.



A. Transportation and Communications Expenditures (Current \$)



B. Transportation and Communications Expenditure Share (%)

**Figure 1: Transportation and Communications Expenditure Trends**