Information Technology and Transportation: Substitutes or Complements?

Oliver, Atara Stephanie

University of Maryland - Baltimore County

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Atara Stephanie Oliver*

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Department of Economics, University of Maryland - Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250

Abstract

The increased availability and prevalence of Information and Communications Technology (ICT) provides opportunities to use such products as substitutes for transportation. Common examples of this substitution are telecommuting, video conferences, and online classes. However, despite the intuitive appeal of a substitution relationship existing between ICT and transportation, prior research has indicated that the relationship between ICT and transportation is quite complex; at times ICT substitutes for travel and at other times ICT and travel complement each other. Therefore, using a Quadratic Almost Ideal Demand System (QUAIDS) model and data from the US Consumer Expenditure Survey and the Consumer Price Index, I analyzed the effect of ICT expenditures on transportation demand. The analysis indicates that ICT may serve as a substitute for air travel, but primarily serves as a complement for

*E-mail: oliver3@umbc.edu

private transportation. Overall the data supports a complementary relationship between ICT and transportation, which indicates that an increase in technology may increase rather than decrease the negative externalities associated with transportation.

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1 Introduction

Even the most cursory observation of society reveals the increasing role that Information and Communications Technology (ICT) plays in the daily lives of many individuals. Within the last two decades, the Internet has developed to the point that many activities that once required consumers to travel, such as banking or attending business meetings, can now be done online. Over this same period, Consumer Price Index (CPI) data indicates that gasoline prices in the United States have increased at a rate far greater than inflation, increasing from an average price of $1.073 per gallon in January 1992 to $3.399 per gallon in January 2012. Because gasoline is used for almost every form of transportation, it would be reasonable to assume that this increase would affect demand for transportation. Therefore, given the increasing prevalence of technological alternatives to transportation, it would seem logical for consumers to choose to substitute ICT for transportation.

In addition to potential cost savings for consumers, there are potential macroeconomic benefits if consumers do choose to regularly substitute ICT for transportation. Due to the important role of oil in the economy, oil price fluctuations are known to have large macroeconomic effects. Research on the macroeconomic effects of oil price shocks indicates that an increase in oil prices decreases GDP, with an oil-price/GDP elasticity of -0.055 (Jones et al., 2004).

While far from the only factor, decreases in consumer demand for goods in response to these oil-price increases partially explains the negative effect on GDP. Therefore, if consumers would rely more on ICT and less on gasoline, it might have a positive effect on macroeconomic stability, in addition to partially shielding those individuals from the harmful effects of oil-price fluctuations.

A decrease in transportation use would also reduce the negative externalities caused by transportation use. Americans' heavy use of transportation results in numerous negative externalities, such as pollution, traffic congestion, and vehicle accidents. Therefore, it is reasonable to assume that if a decrease in the use of transportation can be brought about through substituting ICT, it would have a positive effect on societal welfare. Therefore, it has been suggested that regional planners encourage the use of technological substitutes for transportation, such as telecommuting and teleshopping, in order to reduce demand for transportation (Deakin, 2001).

However, despite these potential societal benefits and the notion of substitutability between these two products being intuitively appealing, previous literature has demonstrated that the relationship between these products is quite complex and that technology may serve as either a substitute or a complement for transportation. Banister and Stead (2004) identify several significant factors that contribute to the complexity of the relationship between ICT and transportation:

1. Megatrends such as globalization and the gradual transition to an information-based rather than industrial-based economy may increase the demand for both ICT and transportation.

2. The increase in ICT may influence consumers to substitute one form of transportation use for another. For example, if one spouse telecommutes rather than commuting to work, it may make the car available for the

other spouse to use for shopping during the day.

3. The availability of ICT may result in decentralization. As individuals move further away from city centers, they may make less frequent trips, but make longer trips each time they travel.

4. ICT use may increase the user's social and business contacts, leading to an increased demand to travel to meet with those contacts.

5. The time saved through the use of ICT may increase the time available for vacations and other travel-intensive activities.

Therefore, the purpose of my research is to investigate how consumers' ICT expenditures influence their transportation expenditures. Using household-level data (microdata) from the 2005 – 2012 Consumer Expenditure Surveys (CES) combined with aggregate price data from the Consumer Price Index (CPI), both produced by the U.S. Bureau of Labor Statistics, I address three questions:

1. Are consumers spending a larger percentage of their budgets on ICT and transportation expenses than they have previously? How have prices for ICT-related and transportation-related goods and services affected consumer expenditures on these goods?

2. Do consumers substitute ICT goods for transportation goods? If so, to what degree and for which transportation goods? How do demographic factors affect these spending choices?

3. What are the potential implications of these spending patterns on societal welfare?

To investigate these issues, I estimate a model using the Quadratic Almost Ideal Demand System (QUAIDS) (Banks et al., 1997), which is explained in further detail below. The QUAIDS model is designed to estimate a demand system consistent with both microeconomic theory and the available expenditure and price data, which can then be used to estimate the own-price, cross-price, and income elasticities of various technology and transportation expenditures. Given differences between transportation practices when traveling away from home versus commuting locally, I will examine transportation expense data from long-distance trips separately. Additionally, I control for demographic factors to determine how these factors influence consumer demand.

1.1 Current Research on the Roles of ICT and Transportation in Society

Data on communications technology ownership and use indicates that the use of these products is increasingly prevalent among American consumers. Total computer ownership has increased dramatically in recent years. While only 54% of households owned a computer in 2001, 79% of households owned computers in 2011. United States Consumer Expenditure data indicates that the average number of computers owned by households similarly increased over that period, from 0.62 in 2001 to 1.29 in 2010. Similarly, the use of the Internet has increased greatly in recent years. Research from the Pew Internet and American Life Project indicates that as of 2010, two-thirds of American adults have a home broadband Internet connection (Smith, 2010a). Additionally, 47% of American adults used laptop computers for wireless Internet access in May 2010, an increase of 21% from April 2009 (Smith, 2010b). Forty percent of adults accessed wireless Internet services from their cellular phones in May 2010, up 25% from April 2009. The survey also found that wireless Internet use varies considerably by age, with 84% of those aged 18-29 being wireless Internet users in May 2010, while only 20% of adults over 65 used such devices.

Given consumers' increased ability to perform a variety of activities from the comfort of one's home using the Internet, and the increasing cost of gasoline, it would be reasonable to assume that consumers would choose to regularly substitute technology for travel. However, the increased availability of resources on the "information superhighway" has done little to decrease congestion on American highways. The 2011 Urban Mobility (Schrank et al., 2012) report indicates that the average American commuter spent 34 hours per year in 2010 commuting due to traffic, just one hour less than the 35 hours spent in traffic in 2000. The cost of the time lost and the fuel wasted across American commuters is estimated to be $101 billion dollars annually, compared to $79 billion (in 2010 dollars) in 2000. The trend of increasing consumer expenditures on transportation is also evident in the Consumer Expenditure data, with an 8.0% rise in transportation expenditures reported in 2011, which is a larger increase than in any other expenditure category.

While the increasing prevalence of ICT enables users to perform many activities that once required travel, the effect of ICT on travel is far from straightforward. Personal travel is typically characterized as belonging to three general categories: mandatory, which includes work-related travel such as commuting to work, or travel related to education; maintenance, such as shopping, banking, and obtaining healthcare; and discretionary, which is traveling for leisure activities (Andreev et al., 2010). Salomon and Mokhtarian (2008) identified several uses of ICT that have personal-travel-related applications: mobile telephones; telecommuting; teleconferencing; teleshopping; and teleservices, which include distance learning and telemedicine; and teleleisure. The proliferation of mobile telephone use among individuals has enabled consumers to hold one-on-one conversations from a variety of locations. This may have the effect of reducing "deadweight trips," which are trips that do not accomplish their intended purpose, but it may also enable consumers to make trips with less advance planning due to the increased ability to contact all relevant parties "on the go." Telecommuting, which is by far the most frequently studied form of ICT regarding its effects on transportation, has been shown by numerous studies to have a substitution effect on transportation (Andreev et al., 2010). However, the prevalence of telecommuting, and its effect on travel, often vary considerably depending on the type of worker (self-employed, salaried employees, distant workers, etc.) and is, therefore, quite difficult to measure (Salomon and Mokhtarian, 2008). Studies of teleshopping and teleservices, however, have had very different results. Most studies examining the effect that the use of ICT had on travel demonstrated a neutral or complementary effect (Andreev et al., 2010).

One area that may have a significant effect on travel but is often overlooked is that of teleleisure. Yet given that leisure travel constitutes between one-third and one-half of total travel (Mokhtarian et al., 2006), this type of travel must be carefully considered when examining the effects of ICT on travel. Many modern leisure activities, from socializing to playing games, are now done online. These leisure activities may take the place of travel. Yet ICT may also lead to an increase of leisure travel by enabling consumers to locate travel bargains or by stimulating the desire to meet online friends. A study of time-use among Hong Kong residents found that ICT use led to more use of transportation for leisure purposes, meaning that ICT served as a complement for leisure travel rather than as a substitute (Wang and Law, 2007). This study is consistent with the other research surveyed by Andreev, Saloman, and Pliskin, which found either no relationship or complementarity relationships between ICT and leisure travel.

On the aggregate level, Choo, Lee, and Mokhtarian (2007) found, in their study of United States aggregated consumer expenditures on ICT and transportation from 1984-2002, that communications had complementary effects on some transportation spending and substitution effects on others, indicating a complex relationship between communications spending and transportation spending. They found that electronic communications expenditures increased as prices increased for non-personal-vehicle transportation, implying that consumers do substitute electronic communications use for public transportation travel, but spending on electronic communications were found to increase as personal vehicle purchases and operating costs increased, implying that consumers may view those products as complements. They also noted that the transportation expenditures were more price- and income-elastic than were the communications expenditures, indicating that consumers view communications expenditures as more essential than transportation expenditures. However, the choice to examine spending on an aggregate level rather than on an individual level left a very small sample size of only 19 aggregated observations. Given that the income, demographic characteristics, region, and other significant considerations affecting consumers vary among the individuals surveyed, treating the surveyed consumers as one entity would not provide a comprehensive assessment of demand for these products and services. Transportation in particular has been shown to have elasticities that vary significantly based on income (Blundell et al., 1993), so an aggregate measurement could yield inaccurate results regarding the elasticity of substitution. Also, because the availability and prevalence of communications technology has increased considerably since 2002, consumer choices regarding ICT and transportation spending may have changed as well.

2 Methods

2.1 Description of Data

The estimation of a demand system using the QUAIDS model requires both consumer expenditure data and price data for each expenditure category. The consumer expenditure data is taken from the US Consumer Expenditure Survey (CES) over the period of 2005 to 2012. The CES consists of two separate surveys—the interview survey and the diary survey. Because the interview survey includes all of the expenses needed for this model, only data from the interview survey will be used. The interview microdata consist of approximately 7,000 household-level observations per quarter. Each household is interviewed for five consecutive quarters on a rotating basis; therefore, one-fifth of the sample is new each quarter. However, since the first quarter interview is designed to collect demographic data, only four of those quarters include expenditure data.

It is worth noting that the term household, in the context of this paper, refers to a consumer unit (CU) as defined by the BLS. A consumer unit consists of people who live together and combine their incomes to make joint expenditure decisions or live together and are related by either blood or marriage. Roommates who live together but do not make joint financial decisions are defined as two separate consumer units, while married couples with separate finances are considered as one consumer unit.

The price data is taken from the Consumer Price Index (CPI). Because the CPI does not provide product-level data, I calculate the demand equations and the elasticities based on aggregated price indexes that combine several similar products into a single price index.

To simplify the calculation process and ease the interpretation of results, I aggregated expenditures from several categories into broader expenditure categories based on similar product or service use and combined them with the appropriate aggregate price category. My aggregated technology expenditure categories are computers, home Internet service, and cellular phone plans. My aggregated transportation categories are private transportation expenditures—which include car payments, gasoline, insurance, and maintenance—airfare, other long-distance public transportation, and local public transportation. I also include a variable that represents expenditures on all other goods and services, and this variable uses the CPI All Items Index as its price index.

2.2 Demand System Selection

The process of estimating the effects of changes in demand for certain products, such as communications goods and services, must begin with the estimation of demand equations derived from consumer choice theory. Numerous flexible demand systems have been proposed to estimate demand curves from consumer expenditure data. In order to determine the best way to model US aggregate consumer expenditure data, Fisher et al. (2001) performed an empirical comparison of eight commonly used demand systems: three locally flexible functional forms, the Generalized Leontief (Diewert, 1971), Translog (Christensen et al., 1975), and Almost Ideal Demand System (AIDS) (Deaton and Muellbauer, 1980) models; three effectively globally regular functional forms, the Full Laurent model (Barnett, 1983), the Quadratic Almost Ideal Demand System (QUAIDS) (Banks et al., 1997), and the General Exponential Form (Cooper and McLaren, 1996); and two semi-non-parametric models; the Fourier model (Gallant, 1981) and the Asymptotically Ideal Model (Barnett, 1998). Out of the eight models, the QUAIDS model stood out as being the superior choice for modeling household-level U.S. consumer expenditure data. When the QUAIDS model was tested, it demonstrated no violations of concavity, and it fit extreme expenditures in the data set better than any other model tested. While the semi-non-parametric models performed better on the forecasting tests, forecasting is not the main focus of this research.

Significantly, Fisher, Fleissig, and Serletis noted that semi-non-parametric models allow for more price flexibility relative to income flexibility, while QUAIDS allows for more income flexibility relative to price flexibility. Therefore, while aggregate data may favor semi-non-parametric methods due to their superior forecasting performance, household-level data, which requires a greater level of income flexibility due to the wide range of incomes found in the sample, may be better modeled with the QUAIDS model. Therefore, the QUAIDS model will be used for this research.

2.2.1 The QUAIDS Model

The Quadratic Almost Ideal Demand System (QUAIDS) model (Banks et al., 1997) was developed to address the need for a demand system that allows for non-linear Engel curves. Murray (2012) notes that the model upon which QUAIDS is based, the AIDS model, is flexible enough to approximate demand functions for both very specific topics, such as demand for soft drinks (Dhar et al., 2003), and aggregated categories of goods such as housing, clothing and food, an example of which is seen in Fan et al. (1995). However, the AIDS model requires that Engel curves be linear, meaning that the expenditure share must have a linear relationship to the logarithm of total expenditure (Deaton and Muellbauer, 1980).

For many goods this assumption is not realistic. Expenditure on certain goods can increase until a certain point as income increases, due to the "luxury" status of those goods, then start to decrease as the good becomes a "necessity" relative to other purchases. Regarding transportation expenditures, Taylor and Houthakker (2010) found that the aggregate expenditure elasticities for transportation were the highest of all 29 general expenditure categories surveyed, implying that transportation expenses are in some sense a luxury, despite some level of expenditure on transportation clearly being a necessity. Blanks, Blundell, and Lewbel (1997) found through an analysis of expenditure data from the United Kingdom that products such as food and fuel had approximately linear Engel curves, while products such as clothing and alcohol had a distinctly quadratic shape, first increasing then decreasing. Previous research based on British data indicates that transportation goods likely share this characteristic (Blundell et al., 1993) Ordinary least squares regression of expenditure and squared expenditure confrmed that transportation expenditure share has a quadratic relationship with total expenditure among individuals in the CES sample, as seen in Figure 1.

ICT products and services—such as cellular phones, computers, and Internet service plans—as well as non-fuel transportation goods and services such as plane tickets and personal vehicle expenditures, intuitively seem more similar to clothing and alcohol than to food or fuel. Both food and fuel would be viewed as necessities at every income level, while products such as clothing or cellular phone plans would likely be viewed as a luxury by lower-income consumers and as a necessity by higher-income consumers.

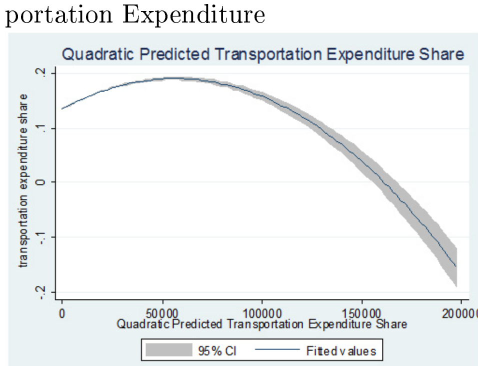

Figure 1: Quadratic Predicted Transportation Expenditure

Since the QUAIDS model is based upon the AIDS model, an understanding of the AIDS model is required to derive a QUAIDS demand system. The AIDS model was designed by Deaton and Muellbauer (1980) to provide a linear approximation to any demand system that is consistent with economic theory and that can be aggregated across consumers. The model is based on the assumption of Price Independent Generalized Logarithmic (PIGLOG) preferences (Muellbauer, 1976), which aggregate the demands of all consumers as if they were made by a single rational representative consumer. As opposed to an earlier model by Gorman (1953) that aggregated consumers based on consumption, Muellbauer defines the representative consumer as being representative in expenditure shares. These preferences can be expressed as:

$$\log M(u, \mathbf{p}) = (1-u)\log(a(\mathbf{p})) + u\log(b(\mathbf{p})) \tag{1}$$

Therefore, the expenditure share for the representative consumer can be expressed as:

$$w_i = \frac{\partial \log M(u_0, p_i)}{\partial logp_i} \tag{2}$$

Where $\mathbf{p}$ is the vector of prices, w_i is the expenditure share for good i, and $\log M(u, \mathbf{p})$ is the natural log of the expenditure function needed to achieve a level of utility "u", $0 \leq u \leq 1$. The functions $a(\mathbf{p})$ and $b(\mathbf{p})$ represent the costs of achieving a certain level of utility. For preferences in the PIGLOG class, $b(\mathbf{p})$ is greater than $a(\mathbf{p})$ so expenditure will increase as utility increases from zero to one. Because the utility function is assumed to increase with expenditure, the function $a(\mathbf{p})$ is designed to represent the minimum expenditure needed for subsistence, while $b(\mathbf{p})$ represents the expenditures at the highest level of utility, which is when utility equals its maximum value of one (Deaton and Muellbauer, 1980). The AIDS model defines:

$$\log(a(\mathbf{p})) = \alpha_0 + \sum_i \alpha_i \log p_i + \frac{1}{2}\sum_j \sum_i \gamma_{ij} \log p_i \log p_j = P \quad (3)$$

$$\log(b(\mathbf{p})) = \log(a(\mathbf{p})) + \beta_0 \prod_i p_i^{\beta_i} \quad (4)$$

Which, when placed into the budget share equation, ultimately results in the AIDS demand function:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i \log(\frac{x}{P}) \quad (5)$$

$$\sum \alpha_i = 1, \sum_i \gamma_{ij} = \sum_j \gamma_{ij} = \sum \beta_i = 0, \gamma_{ij} = \gamma_{ji} \quad (6)$$

Where x is total expenditure (or income), w_i is the expenditure share for the representative consumer, and P is the price index, which is equal to $a(\mathbf{p})$.

The QUAIDS model adds an additional quadratic term to account for non-linear Engel curves caused by differences in expenditure shares among individuals at different income levels. Some expenditures have non-linear Engel curves and therefore require an additional quadratic term while others do not. Therefore, to remain consistent with utility theory, the needed quadratic term must be that of log income (Banks et al., 1997). The QUAIDS model nests both the AIDS model and the Translog model, but through the addition of the quadratic income term it allows goods to be luxuries at some levels but necessities at others. This results in the following QUAIDS expenditure share equation:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i \log(\frac{x}{P}) + \frac{\lambda_i}{\prod_i p_i^{\beta_i}} \left[\log(\frac{x}{P})\right]^2 \quad (7)$$

$$\lambda(\mathbf{P}) = \sum_i \lambda_i \log p_i, \sum_i \lambda_i = 0 \quad (8)$$

Where $\frac{\lambda_i}{\prod\limits_i p_i^{\beta i}}$ is the parameter λ_i divided by $\prod\limits_i p_i^{\beta i}$ from equation (4), which represents the difference between the log expenditure at subsistence level and at the maximum level of utility. Because the expenditure shares at both subsistence level and at higher levels of utility must add up to 100%, the $\frac{\lambda_i}{\prod\limits_i p_i^{\beta i}}$ term, which represents the difference between the expenditure shares at the different levels of utility, must sum to zero when added up for all values of i. Therefore, $\sum\limits_j \lambda_i$ must equal zero.

Given that numerous demographic characteristics can potentially cause changes in consumer spending, the model will also need to incorporate demographic variables and time variables into the analysis. I incorporate demographic variables into the model using Ray's (1983) method of scaling the expenditure function to account for household characteristics:

$$e(\mathbf{P}, \mathbf{z}, u) = \overline{x_0}(\mathbf{z}) \times \Phi(\mathbf{P}, \mathbf{z}, u) \times e^R(\mathbf{P}, \mathbf{z}) \tag{9}$$

Where $e(\mathbf{P}, \mathbf{z}, u)$ is the household's expenditure as a function of the price vector $\mathbf{P}$, the demographic vector $\mathbf{z}$, and utility u. $\overline{x_0}(\mathbf{z}) \times \Phi(\mathbf{P}, \mathbf{z}, u)$ scales the expenditure function to account for demographic characteristics, with $\overline{x_0}(\mathbf{z})$ representing the effect of demographic characteristics on total expenditure and $\Phi(\mathbf{P}, \mathbf{z}, u)$ representing the effect of those characteristics on relative expenditure, while $e^R(\mathbf{P}, \mathbf{z})$ are the expenditure characteristics of a reference household.

In order to ease the fit of these demographic terms into the QUAIDS system, the following parameterization of the terms $\overline{x_0}(\mathbf{z})$ and $\Phi(\mathbf{P}, \mathbf{z}, u)$ is used (Poi, 2012):

$$\overline{x_0}(\mathbf{z}) = 1 + \rho' \mathbf{z} \tag{10}$$

$$\log \Phi(\mathbf{P}, \mathbf{z}, u) = \frac{\prod_{i=1}^{j} p_i^{\beta i} (\prod_{i=1}^{j} p_i^{\eta_i' z} - 1)}{\frac{1}{u} - \sum_i^j \lambda_j \log p_j} \tag{11}$$

Where ρ is a vector of demographic parameters and η_i' represents the ith component of a parameter matrix η.

2.3 Empirical Strategy

By combining equations (7), (10), and (11), I estimate an empirical model that measures expenditures on ICT and transportation and includes time variables while controlling for relevant demographic considerations:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + (\beta_i + \eta_i' \mathbf{z}) \log(\frac{x}{\overline{x_0}(\mathbf{z})P}) + \frac{\lambda_i}{\prod_i p_i^{\beta i} \prod_i p_i^{\eta_i' z}} \left[\log(\frac{x}{\overline{x_0}(\mathbf{z})P}) \right]^2 \tag{12}$$

To calculate the elasticities, one first differentiates the equation with respect to $\log x$ and $\log p_j$ to obtain budget share elasticities Banks et al. (1997). Dividing the budget share expenditure elasticity by $w_i + 1$ results in the expenditure elasticity. Similarly dividing the expenditure share by $w_i - \delta_{ij}$, where $\delta_{ij}$is the Kronecker delta, equal to zero in the case of own-price elasticity and equal to one otherwise.

$$e_x = \frac{\partial w_i}{\partial \log x} \cdot \frac{1}{w_i + 1} = 1 + \frac{1}{w_i} \left[\beta_i + \eta_i' \mathbf{z} + \frac{2\lambda_i}{\prod_i p_i^{\beta i} \prod_i p_i^{\eta_i' z}} \log(\frac{x}{\overline{x_0}(\mathbf{z})P}) \right] \tag{13}$$

$$eij = \frac{\partial w_i}{\partial \log p_j} . \frac{1}{w_i - \delta_{ij}} = -\delta_{ij} + \frac{1}{w_i}\left(\gamma_{ij} - \left[\beta_i + \eta_i'\mathbf{z} + \frac{2\lambda_i}{\prod_i p_i^{\beta i} \prod_i p_i^{\eta_i' z}} \log(\frac{x}{\overline{x_0}(\mathbf{z})P})\right]\right) \times$$

$$\left[\alpha_j + \sum_i \gamma_{ij} \log p_i\right] - \frac{(\beta_j + \eta_j'\mathbf{z})\lambda_i}{\prod_i p_i^{\beta i} \prod_i p_i^{\eta_i' z}} \left[\log(\frac{x}{\overline{x_0}(\mathbf{z})P})\right]^2 \tag{14}$$

The relevant demographic variables are those that can be assumed to have an effect on consumer spending on ICT and/or transportation expenditures. I included time dummy variables in the demographic formula to control for variations across time and variations across quarters. I included a regional variable, defined as the Northeast census region. The Northeast was chosen due to the concentration of large cities in the region, which possibly affects transportation demand. I also included a dummy variable for age, equal to one if the individual is under 35, as well as a dummy variable for education, equal to one if the individual has more than a high-school education.

I aggregate the relevant expenditure categories into small groups of similar products and service for ease of interpretation and to reduce the likelihood of multicollinearity. My aggregated technology expenditure categories are: computers, home Internet service, and cell phone plans. My aggregated transportation categories are: private transportation expenditures, which include car payments, gasoline, insurance and maintenance; airfare; other intercity transportation fares; and local public transportation. I also include a variable that represents expenditures on all other goods and services, which is calculated by subtracting the expenditure on the specified goods from the total expenditure.

Due to the non-linear parameters of the model, I estimate the parameters of the QUAIDS expenditure share equations using an iterated feasible generalized nonlinear least squares estimation. This requires the assumption that the error terms are uncorrelated and have a mean of zero. Given that households may participate in the survey for up to four quarters, exclusive of the initial interview, it is highly likely that some of the error terms, specifically those for different observations from the same household, are correlated with one another. Therefore, I clustered the observations by household to account for this correlation, resulting in 71,075 household clusters. I removed the households with negative or zero total expenditure values from the sample, leaving 201,750 observations.

I estimate parameters for each of the above-mentioned demographic variables and for each time to determine the effects of demographic considerations and time on transportation expenditures. The use of an iterated feasible generalized nonlinear least squares estimation requires the selection of a value for the constant α_0. Given that the expenditure to achieve the subsistence level of utility,represented by the price index P, and P would equal α_0, the minimum value of observed log expenditure is the upper bound for the value of α_0 (Banks et al., 1997). Therefore, I set α_0 equal to 2.7, which is just below the smallest log expenditure value in the sample. Using the price of each product category in the index, I estimate the ρ vector of demographic parameters, the η demographic parameter matrix, parameter γ_{ij} for all product categories, the β_i parameters for the total expenditure divided by the price index, and the parameters λ_i, $\sum_j \lambda_i = 0$, which after being divided by $\prod_i p_i^{\beta i}$ serves as the coefficient for the squared expenditure divided by the price index.

Based on the prior literature, my assumption is that technology expenditures would have an effect on transportation, but the effect would vary based on the forms of technology and transportation. I predict that technology would slightly decrease expenditures on local forms of transportation, due to the substitution of telecommuting and teleshopping for commuting to work and for shopping. However, based on the likely complementary relationship of technology and leisure travel, I predict that technology expenditures would increase expenditures on long-distance travel. Additionally, the technology expenditure share would likely change across the time period. My prediction is that technology expenditure and expenditure shares would increase over time. I predict that overall transportation expenditure share would rise over the time period, and that gasoline expenditure share would increase given the increase in gasoline prices over the period.

3 Results[1]

An analysis of the cross-price elasticities of demand for the transportation and ICT product categories reveals some surprising results, as can be seen in Table I. Computer expenditures were found to substitute for both long-distance travel categories, but were found to be complements for private transportation and for local public transportation, which is the opposite of what would be expected based on prior literature. Internet service expenditures, however, were found to be a substitute for air travel and local public transportation, but a complement for other intercity travel and for private transportation. Cellular phones were found to substitute for all forms of transportation other than the other intercity transportation category, for which they were complements.

It is important to consider that the calculation of the uncompensated cross-price elasticities shown in equation 14 requires both the γ (cross-price) coefficient terms, shown in Table 3, as well as the β and λ (expenditure) coefficient terms, shown in Table 4, in order to understand both the income and substitution effects resulting from changes in the relative prices of the goods in each category. Regarding airfare, the coefficients of γ are statistically significant for the own-

[1] I can provide a full table of QUAIDS results upon request

Table 1: Uncompensated Price Elasticities, at Means

	Air Travel	Other Intercity Trans	Private Trans	Local Public Trans	Computers	Internet	Cell Phones
Air Travel	-0.150	0.939	0.385	0.745	0.172	0.104	-0.011
Other Intercity Trans	4.505	-1.762	-3.474	1.059	1.697	-0.759	-2.519
Private Trans	0.022	-0.022	-0.077	0.023	-0.051	-0.010	0.017
Local Public Trans	1.548	0.459	1.316	-0.067	-1.898	0.710	8.265
Computers	0.281	0.561	-2.379	-1.436	0.124	-1.244	-4.487
Internet	0.220	-0.311	-0.459	0.679	-1.565	-0.976	-1.039
Cell	0.010	-0.163	0.300	1.259	-0.897	-0.165	-0.415

Table 2: Compensated Price Elasticities, at Means

	Air Travel	Other Intercity Trans	Private Trans	Local Public Trans	Computers	Internet	Cell Phones
Air Travel	-0.139	0.942	0.721	0.751	0.179	0.110	0.025
Other Intercity Trans	4.520	-1.759	-3.043	1.066	1.707	-0.751	-2.472
Private Trans	0.027	-0.021	0.054	0.025	-0.048	-0.008	0.032
Local Public Trans	1.556	0.460	1.533	-0.064	-1.893	0.714	8.289
Computers	0.286	0.562	-2.230	-1.434	0.128	-1.242	-4.471
Internet	0.221	-0.311	-0.424	0.680	-1.565	-0.975	-1.035
Cell	0.011	-0.163	0.325	1.259	-0.897	-0.165	-0.412

price elasticity, other intercity transportation, and local public transportation, but not for private transportation or any of the three technology categories. This indicates that there may be no significant substitution effect between information technology and airfare. Regarding airfare and cellular phone expenditures, the uncompensated cross-price effect of cellular phones on air-travel expenditures is slightly negative, while the effect of air-travel expenditures on cellular phones is slightly positive. However, the compensated cross-price elasticities, shown in Table 2, are positive in both cases. This discrepancy is possibly due to the income effect, that an increase in the price of airfare, which has an inelastic own-price elasticity, increasing the expenditure share dedicated to airfare, therefore decreasing the individual's available income and cellular phone expenditure share.

Other intercity transportation, airfare, private transportation, computers, and Internet service were found to have statistically significant cross-price effects. As one would predict, airfare and other intercity transportation were found to be substitutes. However, quite surprisingly other intercity transportation and private transportation were found to be complements. Regarding technology products, computers were found to be a substitute for other intercity transportation, while Internet was found to be a complement. Given that a computer is a major purchase, it is possible that consumers would avoid planning long-distance trips after purchasing a computer. However, given that Internet service is often a regular monthly expense, that concern likely would not apply.

The γ coefficients of private transportation were significant for own-price elasticity, other intercity transportation, local public transportation, computers, and internet service. Local public transportation and private transportation were substitutes, as one would expect. Interestingly, private transportation was found to be a complement for both computers and Internet service. While cellular phone expenditures were found to be a substitute for private transportation, the cross-price (γ) coefficient was not statistically significant. It therefore appears that increased ICT use may lead to increased demand for private transportation.

For local public transportation, the γ coefficients were statistically-significant for airfare, private transportation, computers, and cell phone service. Computers were found to be complements for local transportation, but cell phones were found to be a substitute.

Regarding the technology categories themselves, computers, Internet service, and cell phone service all complements one another, with all but the home-internet/cell-phone relationship being statistically significant. The complementary relationship between computers and Internet service is obvious—computers are used to access the Internet. Similarly, the complementary relationship between computers and cellular phone service seems logical given that consumers who choose to have Internet access may well want to be able to access the Internet when away from home as well, which can be done through using an Internet-enabled cellular phone. Additionally, syncing allows consumers to swap files between their phones and computers, making computers and cellular phones natural complements. Surprisingly, computer products seem to display a positive, statistically significant own-price elasticity. A possible explanation for this could be that the use of aggregated expenditure categories and price indexes does not adequately account for the differences in quality and features of computers produced at different times.

Expenditure elasticities were positive for all categories, indicating that all of the categories contain normal goods. As seen in Table 4, the regular expenditure terms were significant for all goods other than other intercity transportation, and quadratic expenditure terms were significant for all categories. The trans-

Table 3: QUAIDS Gamma Estimates

	Air Travel	Other Intercity Trans	Private Trans	Local Public Trans	Computers	Internet	Cell Phones
Air Travel	0.0043*	0.0047**	0.0031	0.0037*	0.0009	0.0005	0.0001
	(0.0019)	(0.0009)	(0.0017)	(0.0018)	(0.0006)	(0.0005)	(0.0022)
Other Intercity Trans		-0.0008	-0.0032**	0.0011	0.0018**	-0.0008*	-0.0026
		(0.0011)	(0.0009)	(0.0014)	(0.0005)	(0.0004)	(0.0020)
Private Trans			0.1266**	0.0038*	-0.0077**	-0.0016**	0.0015
			(0.0093)	(0.0016)	(0.0017)	(0.0006)	(0.0031)
Local Public Trans				0.0022	-0.0045**	0.0017	0.0199**
				(0.0052)	(0.0014)	(0.0009)	(0.0050)
Computers					0.0036**	-0.0039**	-0.0142**
					(0.0007)	(0.0004)	(0.0026)
Internet						0.0001	-0.0027
						(0.0004)	(0.0015)
Cell Phones							0.0088
							(0.0116)

* p <0.05, ** p<0.01. n = 201,750, (Std. Err. adjusted for 71075 clusters in cuid)

Table 4: QUAIDS Income Coefficient Estimates

	Air Travel	Other Intercity Trans.	Private Trans	Local Public Trans	Computers	Internet	Cell
Beta	0.00228**	0.00011	0.05672**	-0.00420**	0.00212**	0.00032**	0.00239**
	(0.0002)	(0.0001)	(0.0016)	(0.0003)	(0.0001)	(0.0001)	(0.0004)
Lambda	0.00059**	0.00024**	-0.00689**	0.00052**	-0.00019**	-0.00032**	-0.00211**
	(0.0000)	(0.0000)	(0.0005)	(0.0001)	(0.0000)	(0.0000)	(0.0001)

* p <0.05, ** p<0.01. n = 201,750, (Std. Err. adjusted for 71075 clusters in cuid)

portation expenditures for all categories except for private transportation were highly elastic, indicating that expenditures on these categories increase considerably as income increases. Expenditure on private transportation were found to be approximately unit elastic, indicating that the expenditure increases proportionately to income. While computer expenditures were also found to be approximately unit elastic, Internet and cellular phone expenditures were found to be quite inelastic. A possible reason behind the lack of expenditure elasticity for these goods is the small variety of price options available for these goods. Both Internet service and cellular phone services are sold in predefined plans, and once one chooses the highest-level plan, there is little room to spend more. This hypothesis is supported by the fact that these goods have higher expenditure elasticity for households in the lowest expenditure decile, those with total annual expenditures below $14,000, than for those households who have higher total expenditures. Similarly, households in the highest expenditure decile, those with total annual expenditures above $90,000, were found to have a negative expenditure elasticity for those goods, as can be seen in Table 5, indicating that such expenditures are luxuries at lower income levels and necessities at higher income levels.

4 Conclusion

The elasticities discovered through applying the QUAIDS model to transportation and technology expenditures differ from what one would expect from prior literature. While ICT was found to substitute for airfare expenditures, the coefficients of the cross-price terms are not statistically significant. Also, because the data measure expenditures on these items rather than the actual use of these items, the data do not necessarily indicate that consumers who fly more use technology less. While the expenditures on technology products likely vary

Table 5: Expenditure Elasticities, at Means

	Air Travel	Other Intercity Trans	Private Trans	Local Public Trans	Computers	Internet	Cell Phones
All	2.305	2.963	0.905	1.491	1.020	0.243	0.176
Under 35	2.228	3.382	0.884	1.617	1.039	0.011	0.436
Over 35	2.336	2.895	0.908	1.455	1.006	0.289	0.047
Post high-school education	2.108	2.725	0.812	1.925	0.991	0.251	0.066
No post high-school education	3.395	4.092	1.072	1.003	1.099	0.174	0.344
Total expenditure under $14,000	4.116	3.727	1.151	0.889	1.302	0.356	0.537
Total expenditure over $90,000	1.760	1.986	0.737	3.117	0.887	-0.717	-1.187

somewhat according to use—as those who use these products more would likely spend more on them and update them more frequently—computers, Internet, and cell phones clearly have a large fixed-cost component. An alternative explanation could be that consumers who spend more on technology use that technology to find less expensive flights and therefore spend less to fly the same amount as do their peers who do not spend as much on technology.

Computers and Internet service were found to be complements for private transportation, which indicates that technology apparently does not have the desired effect of reducing the negative externalities associated with transportation use. This may indicate that as technology continues to increase, transportation networks will become further strained, an issue that should be considered by state and local officials when planning for future transportation use.

However, it is also important to examine the reasoning behind the complementary relationship. It is possible that Internet use increases leisure travel, as seen in Wang and Law (2007). However, because the CES does not differentiate between leisure and other activities, this cannot be determined with certainty.

Future directions for research would include relating the time spent using technology to technology expenditures. Another unresolved issue is that of the relationship between information technology spending to actual miles traveled in order to determine if those who use technology actually travel less (or more), or whether they pay less for the travel that they do. It would similarly be useful to analyze time-use surveys to relate the time spent using technology to the time spent traveling. Analyzing these issues could help clarify the effect of technology on consumers' transportation decisions.

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