The Changing Nature Of The Telecommunications Industry: Impacts On Demand And Regulation

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Abstract

The telecommunications industry has recently experienced drastic changes. The aim of these essays is to examine how the changes in the industry have transformed consumers' demand for telecommunications services and the impact of these changes on universal service policies.

In the first chapter, my co-authors and I explore the evolution of consumers' demand for telecommunications using a model that extends the traditional (node-to-node) demand structure. We empirically estimate a consumer choice model using household-level observations from 2003-2010. We find that households that are more affiliated with their domicile are more prone toward wireline services while more "on the go" households are more attracted to wireless telephony. The results indicate that subscription to wireline and wireless telephony are substitutes rather than complements. Finally, we find that the quality convergence in wireless and wireline services has contributed significantly to shifts in consumers' telephone portfolios.

In the second chapter, I examine whether subsidies to low-income households promote the goal of Universal Service. In 2005, Lifeline - the federal program designed to promote universal telecommunications services to low-income households, was expanded to cover wireless as well as wireline services. In this paper I utilize a unique household-level data set to examine the impact of Lifeline as well as the impact of its extension to wireless service. The results indicate both the subsidy and its extension to prepaid wireless service have increased subscription rates among low-income households, however at high cost. The counterfactual experiment shows that only one out of eight households that receive the subsidy subscribes to telephone service because of the subsidy.

Finally, the third chapter analyses the demand for international telephone calls using a simultaneous equations model. The analysis draws upon unique data collected for 24 countries over the 2010-2012 period. These data contain traffic from both landline and cellular phones routed through conventional Time Division Multiplexed (TDM) networks and emergent Voice over Internet Protocol (VoIP) technology. The results indicate that mobile prices are negatively correlated with the demand for international calls, while prices for calls via wireline networks and VoIP have no significant impact. The results show that proliferation of broadband has contributed to the growth of international telephone traffic.

INDEX WORDS: Telecommunications; Access; Mobile; Demand; Substitution; Lifeline; Cost-Benefit Analysis

Dedication

I would like to dedicate this work to my loving parents, Elena and Radiy Ukhanev, who encouraged, inspired and supported me all the way through my doctorate studies. My sister Yana Ukhaneva who encouraged me to apply for the Ph.D. program. My advisor John Mayo who made the research process enjoyable. Without his guidance and persistent help this dissertation would not be possible. And most importantly, I dedicate this to Anant Tiwari. His love, support and belief in me helped me to get through the toughest times.

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Table of Contents

Chapter 1

Demand in a Portfolio-Choice Environment: The Evolution of Telecommunications

co-authored with Jeffrey T. Macher, John W. Mayo and Glenn A. Woroch

The emergence and rapid proliferation of wireless telephony and broadband service have introduced the most dramatic transformations in the telecommunication industry since the invention of the telephone in 1876. When Ameritech first introduced cellular service in the United States in 1983, however, few would have imagined its explosive growth potential. After all, the first wireless phones were large, weighing over two pounds each, and airtime prices were nearly $1 per minute.[1] Yet by 2012, the technology had improved significantly and the prices of wireless handsets and subscription services had fallen dramatically. The result: over 300 million wireless subscribers in the U.S. and roughly 6 billion wireless subscribers worldwide.[2] Over 40 percent of all U.S. households today are wireless-only.[3]

The rapid pace of consumer demand, technology and public policy changes in this industry has raised a number of important questions that economists have only recently begun to address. Prominent among these questions is how the presence of wireless telephony affects households' choices as they seek to have their communications needs met. Insights into this question promise, in turn, to shed light on a

[1] Mayo and Woroch (2010).

[2] International Telecommunication Union (2012).

[3] See Blumberg and Luke (2013). Following their terminology, we refer to "wireless" as what alternatively is termed "mobile", "cell", or "cellular" service.

number of current economic policy questions, including whether wireline and wireless services are better described as complements or substitutes, whether traditional public policy efforts to promote wireline subscription to the public switched network are necessary in light of the rapid wireless services adoption, and whether competition between wireline and wireless platforms is sufficient to warrant a "light-handed" approach to industry regulation. Additionally, the emergence of wireless technologies raises broader questions regarding the potential for improved efficiencies in specific industries, such as health care, education, insurance, agriculture and fishing, as well as to the broader economy.[4]

Two streams of economic research have emerged which provide some assistance in addressing the issue of household telephony choices in an environment that includes wireline and wireless options. The first is a rich literature on the demand for wireline telecommunications.[5] The second is a more recent literature on the diffusion of wireless telephony.[6] While both research streams are informative, neither captures the rich evolution of consumers' decisions regarding their telecommunications portfolios over the past decade. In particular, given the dramatic evolution of wireline and wireless services, natural questions arise regarding the economic motivations driving adoption when consumers now have multiple options to satisfy their communications needs, including wireline service only, wireless service only, both wireline and wireless services, and neither wireline nor wireless service.

[4]For industry-based studies of the impact of advanced telecommunications, see, e.g., Brown and Goolsbee (2002), Jensen (2007) and Aker (2010). See Röller and Waverman (2001) for a study of the macroeconomic consequences of the deployment of advanced telecommunications.

[5]For a detailed review, see Taylor (2002).

[6]Vogelsang (2010) provides a thorough review of the diffusion of wireless telephony, including studies using microdata from the early 2000s that seek to estimate evidence of consumer substitution across fixed (wired) and mobile (wireless) services. See, e.g., Rodini, Ward and Woroch (2003) and Ward and Woroch (2010). For a literature survey of economic issues related to the wireless telephone industry, see Gans, King and Wright (2005).

In this paper, we take a step toward understanding the evolution of telecommunications demand in the context of an environment in which consumers face a portfolio choice. We do so by first developing a simple model of household choice for alternative platforms that satisfy their communications needs. One alternative is a high quality wireline platform that provides telecommunications services between wired nodes, but is incapable of providing communications for consumers who are not physically located at such nodes. Another choice is (initially) a lower quality wireless platform, but offers consumers the ability to communicate while away from the wired nodes. Other household choices include the selection of both platforms or neither platform. Our model provides insights into the household and network characteristics that are likely to arise as key determinants of the choices that households make regarding how to satisfy their communications needs. We also explore conceptually the implications and interpretations of consumer patterns of substitution across platforms in the face of alternative prices. This approach allows us to frame an empirical analysis that explores both non-price and price determinants of demand, including the substitutability or complementarity of wireline and wireless services.

Given this model, we then draw upon a large and unique survey of household-level communications platform choices over 2003-2010 to empirically model households' decisions to adopt wireline services, wireless services, both services, or neither service. The estimations provide consistent support for the conceptual framework. In particular, households whose characteristics indicate greater spatial mobility of household members are significantly more likely to gravitate toward portfolio choices that include wireless telephone service. And conversely, households whose characteristics signify greater attachment to their homes are more attracted to wireline telephone service. Our empirical analysis also provides strong evidence that wireless telephony has become a close substitute for wireline telephony over the 2003-2010 period.

1.1 A Model of Consumer Choice in a Wired and Wireless Environment

1.1.1 Substitution Patterns: Nonprice Considerations

Consumers' demand for telecommunications services is a consequence of the desire both to be able to transfer information (i.e., voice, data or video) to others and to be able to receive information from others when sufficiently spatially separated to make direct communications difficult. Historically, telecommunications has been available only at fixed (wireline) nodes, so telephone calls from one consumer to another were characterized by exact physical locations. Within this context, models of telephony demand emerged in the 1970s. Over time these models have sought, for example, to capture the essence of network externalities [e.g., Rohlfs (1974)], to model consumer demand in the presence of multiple nonlinear pricing options [e.g., Train, McFadden and Ben-Akiva (1987)], and to model the role that local and long-distance service boundaries and pricing play on telecommunications demand [e.g., Martins-Filho and Mayo (1993)].

While advancing understanding of the demand for traditional telephone services, these models have not typically allowed for consumer preferences to reflect a desire (or an ability) to communicate away from fixed nodes. The emergence of wireless telephony, however, provides the opportunity for a broader description of consumer demand. In particular, while a consumer may retain the demand for wireline communications, she may also gain utility from being able to reach other consumers who are not at a wireline node. Similarly, a consumer may also gain utility from the ability of another consumer to reach her while she is away from her node.[7]

[7] It is also possible that wireless service may not only afford mobility, but also enhance communications services breadth. This would happen, for instance, if wireline broadband service was unavailable while broadband service was available via wireless technologies.

That is, communications demand was driven by the utility of a consumer i, located at her node, to communicate with another consumer j, $j = 1 \ldots m$, located at her node, by either making or receiving telephone calls between i and j.[8] The emergence of wireless telephony, however, provides the opportunity for a broader description of consumer demand. In particular, while consumers may retain the demand for N_i to N_j communications, they may also gain utility from being able to reach other consumers who are not at a wireline node. Similarly, a consumer i may also gain utility from the ability of another consumer j to reach her while she is away from her node.[9]

Thus, consider a household with $N = \{1, ..., n\}$ members. Each household member n_i has a "community of interest" consisting of $M_{ik} = \{m_{i1}, m_{i2}, ..., m_{ik}\}$ other non-family members. At any moment in time, a household member i may get the urge to communicate with family member j or a member of her community of interest m_{ij}.[10] This urge occurs randomly and independently of a person's subscription decisions and her present location (at home or away). For simplicity, suppose that communications between person i and other family members and members of the community of interest are undifferentiated, so we allow j to index both household members and community of interest members. If i is able to connect with j she derives utility u_{ij}. As the receiver will also be affected by the call, let v_{ji} be the utility to j if she is called by i. It is reasonable to assume the caller has more to gain than the receiver ($i.e., u_{ij} > v_{ji}$) if only because the caller was incited to initiate the call before the receiver did so.

[8] Of course, households also may place value on the option to make or receive calls between nodes.

[9] It is also possible that wireless service may not only afford mobility, but also enhance communications services breadth. This would happen, for instance, if wireline broadband service was unavailable while broadband service was available via wireless technologies.

[10] We abstract from the role that prices may play in rationing calling intensity. Specifically, because most wireless subscriptions are for "buckets" of minutes, the marginal price of an additional call is zero unless the subscriber has exhausted the minutes allotted in the bucket. We thus consider the effective marginal price of usage to be zero so that every urge to call is unconstrained by price.

In fact, the receiver may not want calls from certain callers (e.g., telemarketers) in which case $v_{ji} < 0$. The utilities to both the caller and receiver are assumed to vary depending on the quality of the wireless connection relative to calls made using a landline telephone (which is the assumed default).

We further assume that individual i is at home with probability ϕ_i and away from home with complementary probability $[1 - \phi_i]$. Wireless telephony service is equally available at home or away but not with perfect certainty or high quality. For instance, the cellular network may be unable to establish a connection in the user's location either because of carrier coverage area gaps or because of carrier signal weakness (as when a user is in a building). Let λ_i be a quality variable, measuring the probability that individual i connected to a mobile carrier's network and is successfully able to place and receive mobile calls. The size of λ_i will depend, among other factors, on the capacity of the local wireless network. Finally, we assume that individuals while at home utilize their landline telephone for calling family members and members of their community of interest.

Thus, the utility of i in a wireline-only world can be fully characterized by:

$$\mu_i = \sum_j \phi_i \phi_j (u_{ij} + v_{ij}). \tag{1.1}$$

Allowing for the possibility of wireless communications, we can now represent a consumer i's utility from telecommunications services more fully by:

$$\mu_i = \sum_j \phi_i \phi_j (u_{ij} + v_{ij}) + \sum_j [1 - \phi_i] \lambda_i \phi_j (u_{ij} + v_{ij}) + \\ + \sum_j \phi_i [1 - \phi_j] \lambda_j (u_{ij} + v_{ij}) + \sum_j [1 - \phi_i] \lambda_i [1 - \phi_j] \lambda_j (u_{ij} + v_{ij}), \tag{1.2}$$ [11]

where $j = 1, ..., n + k - 1$.

Equation (2) represents the utility to i of all i to j communications, which is the sum of the utilities (1) from i's wireline to j's wireline; (2) from i's wireless to j's wireline; (3) from i's wireline to j's wireless; and (4) from i's wireless to j's wireless, respectively. Note, that if i does not have a landline, it is equivalent to $\phi_i = 0$; if i is not subscribed to a wireless service it is equivalent to $\lambda_i = 0$.

This specification highlights several salient features that we capture in our empirical analysis. First, equation (2) points to an important role of the mobility of both i and j in the realization of i's utility from wireless service subscription. For instance, note that as ϕ_i approaches 0, the value of the first and third expressions in equation (2) approach zero, respectively. That is, the ability of i to realize utility from communications with j while i is away from her home is contingent upon having a mobile subscription. Alternatively stated, the value of mobile subscriptions will increase the greater the likelihood that i and j are away from their home. If, on the contrary, ϕ_i is rather big, the value of the second and forth expressions in equation (2) approach zero. In other words, if i spends the majority of her time at her node, subscription to mobile service might not add extra value to i's utility.

[11] We follow the convention first established by Rohlfs (1974, p. 20) in assuming that interrelationships between the demand for telecommunications services and other non-communications services purchased by consumers can be ignored. Similarly, we eschew (for the moment) a discussion of the effects of pricing on consumption patterns. We return to this below, however, in Section 2.2.

Second, note that in the event j is not subscribed to a wireless service ($\lambda_j = 0$) it effectively eliminates the latter two terms in equation (1). If household member i particularly values communication with j and ϕ_j is low the marginal utility to i from j's subscription to a mobile service may therefore lead to inter-personal "side-payments" to support j's subscription even when, absent those payments, j would chose not to subscribe to a mobile service. Such side-payments are most frequent between family members. The value of λ_j also highlights a more general network externality effect. Specifically, the value to i of wireless subscription will depend on the ability to communicate with members of her family and community of interest even while those members are away from a landline telephone, thus making the value to i contingent upon j's subscription to the wireless network.

Finally, Equation (2) makes it apparent that variations in λ_i and λ_j, reflecting the quality of the wireless networks subscribed to by i and j will affect i's utility from subscription to a wireless network. Lower values of λ_i and λ_j make it less likely, *ceteris paribus*, that i will find it in her interest to subscribe to a mobile network.

To summarize, for consumer i, the incremental utility associated with subscribing to wireless service depends on: (a) whether consumer i has a demand to communicate with other consumers ($j = 1 \ldots n + k - 1$) while i is away from her node; (b) the probability of consumer i being at her node at the time that i to j communications is desired;[12] (c) the ubiquity of wireless coverage; (d) the quality of wireless service

[12] We abstract away from the potential for households to gain utility from asynchronous communications such as voicemail, email, video and file transmissions that are not received simultaneously. We also implicitly assume that the wireless device is "turned on" while individuals are away from their nodes rather than receiving a message and subsequently returning the call at a later time. Incorporating these considerations would involve discounting the utility from fully contemporaneous communications without any harm to the basic approach we adopt here. We also abstract away from the distinction between the called party being at her node from the called party being at any wired node. In our empirical analysis, however, we account separately for these possibilities.

relative to wireline service; (e) the network effect created by others' subscriptions to the telephone network; and, (f) the utility to consumer i of being reachable by the other consumers j when i is away from his node. Our empirical model will seek to capture these demand drivers.

1.1.2 Substitution Patterns: Price Considerations

Turning to the effects of pricing on consumer demand, our goal is to determine the economic relationship between wireline services and wireless services. In particular, we seek to determine whether access to wireless service serves as a complement to, or substitute for, access to wireline service. As such, the central questions are ones of consumers' responsiveness to price changes in nodal wireline services (N) and wireless services (W).[13] Wireline telephone service is typically priced as a lump-sum monthly payment with a zero marginal price per minute of use.[14] Similarly, wireless telephone service pricing plans most typically incorporate allowances for a number of minutes

[13]Our approach here shares a nomenclature with an independent literature in economic strategy that seeks to determine whether particular corporate strategies are substitutes or complements. For example, Braga and Wilmore (1991) examine the issue of the relationship of technological imports and in-house R&D efforts. Within this literature, key insights into questions of substitutability or complementarity are seen to arise from either observed positive or negative correlations in measures of the strategies themselves or in the errors of reduced-form regressions of the strategies. This approach has developed and been refined over the years by a number of contributions, including Milgrom and Roberts (1990), Arora and Gambardella (1990), Arora (1996), Athey and Stern (1998) Miravete and Pernias (2010), and Kretschmer, Miravete, and PernÃŋas (2012). As noted by Arora (1996), this approach is necesitated by the absence of the 'price' of adopting particular strategies. Gentzkow (2007) extends this literature and builds explicit linkages between this general approach and the conventional approach toward substitutability/complementarity issues when price variation is unobserved. Fortunately, as described below, we are able to directly capture price variations across consumers for the various portfolio alternatives and are able to observe consumer reactions to those price variations. In this manner, our approach is more conventionally set within the standard microeconomic assessment of substitutability/complementarity based on observed consumer reactions to alternative prices.

[14]We set aside here the *de minimis* portion of consumers who subscribe to local wireline telephone service on a usage basis.

that have a zero marginal price as long as the consumer's usage does not exceed the allowance. In these circumstances, the consumer's subscription will depend on a comparison of the monthly subscription fees of wireline and wireless services to the amount of consumer surplus enjoyed from wireline and wireless usage, after consumers have paid their respective monthly fixed charges.[15]

Let P_N represent the prevailing price of wireline telephone service in the household; and let P_{Wi} represent the prevailing price of wireless service for household member i. Individual households maximize the utility gained from wireline and/or wireless communications relative to the cost of these services for all household members:

$$\max\{\sum_i(\mu_i - P_{Wi}) - P_N\} \tag{1.3}$$

Based on the household's maximization problem stated by equation (3) we can estimate the probability of each household to subscribe to (1) no telephone (π_0), (2) wireline service (π_N), (3) wireless service (π_W), or (4) both wireline and wireless services (π_{NW}).

To generate insights into the degree of substitutability or complementarity of consumers' demand for wireline and wireless services we explore how the probabilities of subscription are affected by variation in the prices of wireline and wireless services. In this regard, we focus on the (subscription-based) quantities of wireline services ($Q_N = \pi_N + \pi_{NW}$) and wireless services ($Q_W = \pi_W + \pi_{NW}$). We can then define the economic relationship between nodal wireline and wireless services as:

[15] See Taylor (2002).

$$\frac{\partial Q_W}{\partial P_N} = 0 - \text{Wireline and wireless services are independent,}$$

$$\frac{\partial Q_W}{\partial P_N} > 0 - \text{Wireline and wireless services are substitutes,}$$

$$\frac{\partial Q_W}{\partial P_N} < 0 - \text{Wireline and wireless services are complements.} \quad (1.4)$$

1.2 Empirical Setting and Data

To estimate consumer decisions regarding their portfolio of telecommunications choices, we begin with a unique micro-level database assembled by the National Center for Health Statistics (NCHS), which operates as part of the Centers for Disease Control (CDC). NCHS administers the National Health Interview Survey (NHIS) annually as the principal source of information on the health of the U.S. civilian non-institutionalized population. Interviewers visit households and collect data on roughly 75,000-100,000 individuals annually.[16] Our data are over the 2003-2010 period, with nearly 25,000 households surveyed each year. As shown in Appendix A, NHIS-surveyed households generally track U.S. population demographic characteristics closely.[17] Households are queried in this survey regarding their subscription to wireline and wireless telephone services. Of particular interest are questions about whether the household has no telephone, a wireline telephone only, a wireless telephone only, or a wireline telephone and (one or more) wireless telephones.

[16] For a detailed overview, see *http://www.cdc.gov/nchs/nhis/about_nhis.htm*.

[17] To provide additional assurance that our empirical analysis is not unduly affected by the sampling methods of the NCHS, we employ the sampling weights established by CDC as a robustness check to the estimations we report in Section 4. The results we report are substantively unchanged by the application of the sample weights.

While the public use portion of the data are helpful, the specific locations of surveyed households remain confidential. By application to and approval from the NCHS, we gained access to the confidential household data maintained at a secure facility in Hyattsville, Maryland. Using household-level geocodes, we are able to link the NHIS survey data to location-specific data from several public data sources, including the Federal Communications Commission, the United States Census Bureau, the United States Bureau of Labor Statistics and the United States Department of Agriculture. We describe these other data sources below.

1.2.1 Data Overview and Summary Statistics

The combined dataset for empirical analysis includes 189,616 observations over the 2003-2010 period. Table 1 provides summary statistics on households' subscription to wireline and wireless services, while Figure 1 shows the evolution of households' portfolio choices over the 2003-2013 period.[18] Several characteristics of households' portfolio choices are noteworthy. First, the proportion of households not subscribed to any telephony service is small (about one percent) and remains so throughout the sample period. Second, the proportion of households subscribed exclusively to wireline service decreased dramatically from roughly 49 percent in 2003 to just under 9 percent in 2013. Third, the corresponding share of households subscribing exclusively to wireless telephony grew over the sample period from roughly four percent in 2003 to nearly 42 percent in 2013. Finally, households subscribing to both services grew at the beginning of the sample period from 46 percent to a peak of 61 percent in 2007 and has subsequently declined to 47 percent in 2013.

[18] The extended publicly available data for 2011-2013 are available at http://www.cdc.gov/nchs/nhis/quest_data _related_1997_forward.htm. The data shown in Figure 1 are unweighted. Weighted observations yield essential the same pattern as what is reported here.

The data also reveal important subscription pattern differences by household income. Figure 2 shows the evolution of telephone portfolio choices for households that are below the poverty thresholds in each year. By 2013, the share of poor households subscribing to wireless services only (around 57 percent) was significantly higher than the share of all households subscribing to wireless services only (around 42 percent). Similarly, by 2013 poor households subscribed in larger proportions to wireline service only (roughly 13 percent) in comparison to all households (roughly 9 percent).

Finally, the data point to important changes in telephone portfolio choices by household age. Figure 3 shows that the movement to wireless-only consumption has been particularly dramatic for young households (household members less than 31 years old) over the 2003-2013 period. In 2003, nearly 13 percent of young households subscribed exclusively to wireless services and over 85 percent subscribed to either wireline service only or both wireline and wireless services. But by 2013, over 82 percent of young households subscribed only to wireless service, while the share subscribing to wireline only had fallen to approximately one percent and the share subscribing to both services had fallen to roughly 13 percent.

1.2.2 Variables

Our effort to capture variations in observed household telephone portfolio choices focuses on four categories of variables. First, based on the Section 2.1 discussion, we include variables that are designed to capture the degree to which household members are affiliated more closely with their domicile (node), or alternatively are considered more mobile. Second, we incorporate measures of the respective prices of wireline and wireless telephone service, along with measures of household income. Third, we include measures that seek to capture the wireless telecommunications quality relative to the wireline network. Finally, we include measures to account for demographic characteristics of households.[19] We provide a general overview of these variables below, but a more detailed set of variable definitions and sources is provided in Appendix B.

Nodal Variables Several variables are included to capture the degree to which household members are more (less) closely affiliated with their nodal domicile. Because older households typically spend a greater proportion of their time at home,[20] we include several age-related variables. We first account for whether the household includes a retired individual (*Retired Household*).[21] We next account for whether the household consists solely of individuals under age 31 (*Young Household*), between ages 31 and 45 (*Young-Middle Household*), between ages 45 and 64 (*Older-Middle Household*), or over age 64 (*Older Household*). We expect that older or retired households are more closely affiliated with their node and will therefore be more prone to subscribe to wireline service than wireless service. Conversely, we expect that younger households are attracted in greater proportions to wireless service, as it enhances their abilities to communicate while being "on the go". While more mobile lifestyles among younger households may be thought to create greater attraction to wireless telephony than older households, it is also possible that older consumers are leary of "new" technologies, and will remain loyal to wireline telephony longer than younger households. To allow for this potential, we also account for whether an older household is also

[19]As implied by equations (1)-(4) above, the conceptual possibility of network externalities may also drive consumer demand among telecommunications users. Because network subscription rates within our sample are very high (consistently in excess of 98 percent), we choose as a practical matter to not pursue these potential effects which are likely to be *de minimus* at subscription levels approaching 100 percent.

[20]Bureau of Labor Statistics (2011).

[21]We alternatively substituted this variable with one that accounted for whether the surveyed household included a member that draws Social Security benefits. There was virtually no change in the subsequent empirical results.

wealthy (*Wealthy Retired Household*).[22] We expect that wealthier elderly households are more mobile and less intimidated by new technologies, thereby enhancing wireless telephony subscription.

We also account for household nodal demographics by including measures of whether the household has children (*Children*) and whether any children are students (*Student*). Our expectation is that parents place high priority on "anywhere, anytime" communications with children and students, and will accordingly have enhanced demand for wireless services relative to households without children and students. At the same time, children and students create greater attachment to the family domicile, so we also expect that children and students will create a greater propensity for the household to subscribe to wireline service.

A unique feature of our data is that it includes measures of the health of household members. To take advantage of this information, we account for potential health-related impacts on households' telephone portfolio choices. In particular, we account for households that have a health-impaired youth (*Limited Youth*) or health-impaired adult (*Limited Adult*). Our expectation for the former is that such households have a greater demand for "anywhere, anytime" communication and are therefore more inclined to include wireless telephony in their portfolio, while our expectation for the latter is that such households have a stronger nodal presence and corresponding need for wireline service.

We also account for the working status of the household via several variables. We first account for the ratio of household members employed outside the home (*Ratio Working*). We suggest that work-related matters take household members away from their domicile, making nodal wireline service less attractive and wireless service more

[22] In an alternative specification, we accounted for the education level of the primary respondent in the retired home. The results are similar to those that we report below.

attractive. We also account for whether any household member is employed part-time *(Part-time Employed)*. Given the mobile nature of such households, we expect that part-time employment is associated with an enhanced propensity to subscribe to wireless service. But a household member that is only employed part-time signals greater attachment to the domicile, and therefore likely enhances wireline service demand. We also account for whether a member of the household has self-identified as a housewife (*Housewife*) to examine whether this creates a greater nodal presence and, hence, attraction to wireline services.

Given the efficiency gains from the wider reach [c.f., Jensen(2007)] and the security benefits of mobile telephony in rural areas, we include a measure of the degree to which the household is located in more sparsely populated areas. In particular, we include a variable to capture the population density of the county within which the household resides (*Population Density*). We expect that for a given wireless infrastructure quality level, the propensity of rural households to subscribe to wireless telephony will be enhanced.

Finally, we account for domicile ownership using an indicator variable that differentiates between households that own their home versus rent (*Own House*). Our expectation is that ownership signals greater nodal attachment, with a corresponding increase in the propensity toward wireline telephony services.

Price and Income Variables   Prices are at the heart of demand theory. Accordingly, we include measures of the individual prices of wireline and wireless services. To capture variations in wireline service prices, we begin with 2002 data on the basic flat monthly charges by wire center throughout the U.S.[23] Because the areas served by

[23]These data were graciously provided to us by Greg Rosston, Scott Savage and Bradley Wimmer. See Rosston, Savage and Wimmer (2008) for a detailed description. While many local telephone companies offer local measured service in which customers pay a smaller

wire centers are not typically contiguous with county boundaries, we use population weights within individual wire centers to construct a weighted price by county for residential landline service throughout the U.S. To update these data for the larger sample period, we utilize the Federal Communication Commission's (FCC) "Reference Book of Rates, Price Indices, and Household Expenditures for Telephone Service" (Reference Book). In particular, the Reference Book reports the results of an annual survey of local monthly fixed telephone rates for 95 cities throughout the U.S. The year-to-year values of Pearson correlations for prices in these cities are very high, averaging .96 across for the relevant time period, indicating that the principal source of wireline rate variation is captured by our spatial disaggregation of prices at the sample period beginning. Accordingly, *Wireline Price* is updated by the values of Consumer Price Index (CPI) for local exchange service for the 2003-2010 period.[24]

We also include the price of wireless telephone service subscription. While numerous wireless subscription plans exist, they most generally entail a flat rate charge for a "bucket" of minutes.[25] For consumers whose usage levels remain within the purchased bucket, the price can be taken as the average monthly expenditure for the service.[26] Data on the average monthly revenue per user (including roaming

monthly subscription charge and (after a call or minute allowance) pay a marginal charge per minute or call, industry sources report that the percentage of customers who avail themselves of this option is *de minimus*. Accordingly, we focus on consumers' choices based on variations in flat monthly rates.

[24]Robustness checks of our estimations that employed alternative price measures, such as measures of annual telephone CPI variations or CPI ratios for local and wireless telephone service, gave results that are very similar to those reported below.

[25]Our price measurement captures the fact that the prices of calling from a wireless or wireline telephone are invariant to the type of telephone being called. While the price for wireless calling is generally invariant to the identity of the carrier of the customer being called, during the timeframe of our data, a few plans involved differentially lower prices for consumers making calls to subscribers of the same wireless provider. We are unable to capture this variation.

[26]Because there are numerous wireless carriers offering service in the United States, each with a number of wireless pricing plans, our measure of the price of wireless service is a

charges and long distance toll calling) were provided to us by the Cellular Telephone and Internet Association (CTIA). We rely upon *Wireless Industry Indices*, a semi-annual survey conducted by CTIA of its member companies. In the survey, data were received by companies representing over 95 percent of all U.S. wireless subscribers, and are provided for the 2003-2010 period. While wireless prices are typically geographically invariant, state and local taxes impose spatial variations in the prices paid by consumers in different locales. To capture these variations, we incorporate state and local tax data provided by the Committee on State Taxation (COST). The data are derived from a series of studies conducted by COST, beginning in 1999 and repeated thereafter every three years (i.e., 2001, 2004, 2007 and 2010),[27] which report the prevailing state sales tax rate inclusive of general sales taxes. Local tax rates for each state were taken to be the average between those imposed in the largest city and the capital city. Federal taxes were reported separately. Any flat fees (e.g., 911, Universal Service Fund) were converted to percentages based on average monthly residential bills. In the first two reports, a single tax rate was provided that blended the state and local taxes applied to wireline local and long distance service, and mobile service. In later reports, taxes levied specifically on wireless service were reported separately. After incorporating state and local taxation variations, our measure of *Wireless Price* entails both spatial and inter-temporal dimensions over the relevant period.[28]

composite measure of these plans. While it would be ideal to access individual firmsâĂŹ pricing plans and to yoke this information with subscription decisions of the individual households in our database, this level of granularity is unavailable. Accordingly, our measure necessarily glosses over the ability of households to endogenously adopt one pricing plan, or firm, over another.

[27]See COST (1999, 2002a, 2002b, 2005a, 2005b) and Mackey (2008, 2011).

[28]We examined alternative constructions of the wireless price variable in the estimations reported below with essentially no substantive differences from those reported here.

As is common in modern demand estimation, we consider the potential endogeneity of prices which in our case may most directly be thought to arise either from omission of relevant exogenous variables (or product characteristics) or from a causal feedback from observed demand on prices. In the case at hand, however, potential endogeneity concerns are tempered somewhat by two considerations. First, while a common source of endogeneity bias arises from the omission of relevant independent variables, our model includes a wide-ranging and substantial number of explanatory variables that may reasonably be thought to collectively mitigate this source of endogeneity bias. Second, in our case, feedback from observed demand on prices is mitigated by the particular price-setting mechanisms in the telecommunications industry. Specifically, wireline prices are determined by the regulatory process, which in large part is driven by supply-side (cost) considerations. This is most obviously true for traditional rate-base/rate-of-return regulation. It is also true, however, for price cap regulated firms, whose initial prices under price cap regulation were most often set by existing rates that were established under rate-of-return regulation. Subsequent price changes under price cap regulation have most typically been driven by changes in measures of general inflation (e.g., the CPI) and productivity changes, neither of which tend to be driven by market demand. Similarly, geographic variations in the price of wireless telephony are captured by variations in state and local tax differences, which are, again, not driven in any obvious way by market demand and are exogenous to the carriers. While these considerations help ameliorate endogeneity concerns, as described below we nonetheless incorporate econometric methods based on Rivers and Vuong (1988) and Petrin and Train (2010) to assure the integrity of the parameter estimates and their corresponding statistics.

Drawing on the NHIS survey data, we also include measures of household income. Household income is categorized relative to an annual poverty threshold using four dichotomous variables. Household income below the poverty threshold (*Income1*), between one and two times the poverty threshold (*Income2*), between two and four times the poverty threshold (*Income3*), and more than four times the poverty threshold (*Income4*) are relevant categories.

Quality and Network Effects Variables   Consistent with Section 2, we seek to capture both intertemporal and geographic variations in the relative quality of wireline and wireless services. Given that wireline service has been engineered to very high levels with *de minimis* blocking rates over our sample timeframe, we principally focus our efforts on quality variations in wireless services. Wireless service quality is affected by both topographical characteristics of the local calling area and the extent of infrastructure build-out. We accordingly gathered data from the United States Geological Survey (USGS) on the extent to which the hilliness or mountainous nature of the local terrain may impair wireless communications quality. *Mountainous* is coded on a 21 point scale ranging from flat plains (1), to open low hills (13), and to high mountains (21). We also account for the provisional challenges of high quality wireless service poised by large bodies of water, and accordingly gathered data from the United States Department of Agriculture (USDA) to account for the percentage of the household's county that is water (*Water*).

As noted in Section 2, the quality of wireless services may suffer either from lack of geographic coverage or from insufficient capacity relative to demand (leading to dropped calls). Wireless industry infrastructure grew significantly over the 2003-2010 period, with corresponding increases in the ubiquity of coverage and call quality. To capture this variation, we include a measure of the number of cellsites deployed over time (*Cellsites*).[29] We also account for the potential "reflection problem" identified by Manski (1993) that can arise when the average behavior in a population influences the behavior of individuals within that population. In our case, the question arises whether the observed distribution of cellphones among an individual's "community of interest" might provide a network effect as identified in equation (2). We allow, alternatively, two variables to capture any such network effect. Our broader measure is the nationwide deployment of cellsites, which serves as a proxy for the ability of an individual to reach other mobile subscribers. A more narrow measure, in the spirit of Goolsbee and Klenow (2002) is the number of cellphone subscribers within the Economic Area of the household.

Finally technological changes over the past decade have brought notable and corresponding changes to the versatility (quality) of wireline telephony. Specifically, during the first decade of the 2000s, wireline broadband was increasingly deployed across the United States. Concurrent with the deployment of wireline broadband, providers of both telephone service and cable television began to introduce bundled offerings of these services with high-speed internet access.[30] To account for the potential demand effects of this increased versatility of the wired connections into households, we intro-

[29]In the initial years of cellular telephony, cell sites were typically large stand-alone towers. Over time, providers have deployed quality and capacity enhancing antennae on large buildings, utility poles, water towers, etc., so that "towers" are no longer the most accurate measure of wireless capacity. We therefore draw upon a broader measure of cell sites made available by CTIA, which includes repeaters and other cell-extending devices but excludes microwave hops. Because the specific cell site locations are proprietary, we are unable to account for their geographic distribution. More recent deployments of wireless repeaters and antennae have greater coverage and capacity-enhancing characteristics than earlier vintage deployments. Also, wireless network capacity depends upon the "back-haul" capacity of cell sites which carry wireless traffic to the landline network. Increasingly, such "back-haul" is provided by high-capacity fiber which dramatically increases the ability of specific cell sites to handle larger volumes of voice, data and video traffic. Accordingly, our count of cell sites may underestimates the actual wireless capacity and quality increases over time.

[30]See Prince and Greenstein(2013)

duce *Wireline Broadband* which measures the proportion of households within a state over time that subscribe to wireline broadband services.[31]

Demographic Variables Finally, the existing literature has identified a number of demographic characteristics that affect the likelihood that households subscribe to the "telephone" network. Riordan (2002) surveys this literature, and also independently verifies several demographic factors as contributing to households' propensities to subscribe to wireline service. We accordingly account for households' racial composition (*White, Black, Hispanic, Asian, Indian,* and *Chinese*), gender composition (*Female Household* and *Male Household*), and marital status (*Divorced*) as controls.

1.3 Estimation and Results

To provide a better understanding of consumers' selection of a portfolio of available telecommunications services, we first report correlations between household's subscription to wireline and wireless telephone services. The second column of Table 2 reports tetrachoric correlations for households' decisions to adopt wireless and wireline services, respectively.[32] These estimates represent simple correlations between households' decisions to adopt wireline services with their decisions to adopt wireless services (1 if "yes", 0 if "no"). The pattern of correlations is consistently negative:

[31] As a robustness check, we also drew directly on state-level data collected by the FCC over the 2008-2010 period on households that explicitly subscribed to wireline telephony as part of a bundled offering. The results of this alternative estimation are substantively invariant to those reported in Section 4 below, but involve sacrificing approximately 100,000 observations over the 2003-2007 period. Accordingly, we report our the estimations using *Wireline Broadband* in Section 4 below. In addition to our measure of wireline broadband, we also sought to incorporate the potential demand effects of the emergence of wireless broadband. Unfortunately both the novelty of this phenomenon and inconsistent data collection methodologies by the FCC prohibited our use of such a measure in the estimations.

[32] Tetrachoric correlations are developed for two normally distributed variables that are both expressed as dichotomous. See Greene (2012), p. 741.

households that adopt wireless telephony are less likely to adopt wireline telephony ($\rho = -.53$). The observed correlations are statistically significantly different from zero at the .01 level. As seen in Table 2, moreover, this pattern of negative correlations holds not only for the entire sample of surveyed households but also within each sample year and across all income levels, with the largest negative correlations occurring in the lowest income households.

Table 2 also reports the partial correlation coefficients between wireline and wireless consumption, after controlling for a number of variables, including price, income, demographic variables (*Female/Male Household, Black, Divorced*), nodal variables (*Young Household, Young-Middle Household, Older-Middle Household, Children, Student, Own House, Ratio Working, Part-Time Employed, Retired Household, Wealthy Retired Household, Housewife, Limited Youth, Limited Adult, Unrelated Adults, Population Density)*, and wireless telephony quality variables (*Cellsites, Water, Mountainous, Wireline Broadband*). Column 3 indicates that the relationship between wireline and wireless consumption remains negative ($\rho = -.37$) and is highly statistically significant (even after controlling for several other correlates). The negative correlations again hold not only for the entire sample but also for each year (with the exception of 2003) and income level, with the highest (negative) correlations observed at the lowest income levels.

While these simple correlations are consistent with the substitutability of wireline and wireless services, the presence of correlations of unobserved tastes and preferences across consumers may also account for these observed patterns. Consequently, it is necessary to parse out the effects of these correlations from the true substitutability or complementarity of the services in question. It is to that effort that we now turn. Our approach embodies two identification-enabling features. First, unlike Gentzkow (2007), we are able to explicitly account for consumer reactions to observed price variations. Second, our econometric approach explicitly accounts for the potential for observed correlations in the error structures for consumers who are making their telephone portfolio decisions.

To parametrically investigate the empirical relationship between wireline and wireless subscriptions, we employ several discrete choice models. In any discrete choice analysis, the first step is to identify the available choice set. For our purposes, we assume that both wireline and wireless services are in the choice set, as is the option to not subscribe to any telephone service.[33] As described in Section 2, we seek to understand the decisions of households to adopt (or not) either wireline or wireless service.

1.3.1 Bivariate Probit Model

We begin with a simple specification of household decisions to adopt (or not) wireline service and, potentially independently, adopt (or not) wireless service. The results of two probit regressions are reported in Model (a) of Table 3. The first regression estimates households' decisions to adopt wireline service, and the second regression estimates households' decisions to adopt wireless service. The key assumption underlying these probit estimations is that the decisions to adopt wireline service and wireless service are unrelated. To test this proposition, we allow for the possibility that the error structures across these equations are related.[34] We subsequently estimate a bivariate probit model which yokes the decision to adopt (or not) wireline and wireless services, respectively, by accounting for common correlation (ρ) between the

[33]To test the validity of this assumption, we examined data in the 2003 âĂIJAnnual Report and Analysis of Competitive Market Conditions With Respect to Commercial Mobile ServicesâĂİ published by the Federal Communications Commission. This report examines, *inter alia*, geographic patterns of wireless deployment in the United States. It presents data that mobile coverage, while not abundant with carriers in 2002, was geographically widespread.

[34]See Greene (2012), p. 738.

error structure in the two equations.[35] The estimation results are shown in Model (b) of Table 3, and reveal a strong negative correlation ($\rho = -.52$) in the error structure from the two equations that is significantly different from zero ($p = .01$). The hypothesis of independence of these decisions is therefore strongly rejected. The negative and statistically significant correlation indicates that positive random errors to the wireless subscription equation are associated with negative random errors to the wireline subscription equation. Because this association is, by construction, through the error structure no causality can be inferred. Moreover, as demonstrated by Miravete and Pernias (2010) any inferences regarding the substitutability or complementarity of the services based on correlations of the error terms is inapt. The results nevertheless strongly reject the hypothesis that these decisions are made independently, indicating that the bivariate model is prefered to the estimation of two independent probit equations.

To address the endogeneity issues mentioned above we implement Rivers and Vuong's (1988) two-stage conditional maximum likelihood (2SCML) estimation of the probit and bivariate probit models. In our case, the models are estimated using the following system of equations:

$$y_{it} = \sum_{j=N,W} \beta_j Price_{ijt} + \gamma_k X_{it} + \gamma_m Z_{ijt} + \epsilon_{it}, \tag{1.5}$$

$$\tilde{y}_{it} = \sum_{j=N,W} \kappa_j Price_{ijt} + \xi_k X_{it} + \xi_m Z_{ijt} + \tilde{\epsilon}_{it}, \tag{1.6}$$

[35]For an earlier application of the bivariate approach, see Augereau, Greenstein, Rysman (2006) who model Internet Service Providers' propensities to offer 56K service by utilizing an "X2" modem, a Flex modem, both or neither.

where y_{it} and $\tilde{y}_{it}$ are dummy variables which equal to 1 if a household is subscribed to wireline (respectively, wireless) service at time t. $Price_{ijt}$ is the price faced by household i for service j at time t, X_{it} is an $k \times 1$ vector of demographic and nodal characteristics of household i in year t; Z_{ijt} is an $m \times 1$ vector of quality variables for household i for telephone option j $(j = N, W)$ in year t and ϵ_{it} and $\tilde{\epsilon}_{it}$ are error terms.

Allowing for the potential endogeneity of $Price_{ijt}$, we first estimate

$$Price_{ijt} = \tau_k X_{it} + \tau_m Z^{'}_{ijt} + \upsilon_{ijt}, \tag{1.7}$$

and recover the estimated residuals $\hat{\upsilon}_{ijt}$ from equation (12). This in turn allows us to estimate

$$y^{\star}_{it} = \sum_{j=N,W} \beta_j Price_{ijt} + \gamma_k X_{it} + \gamma_m Z_{ijt} + \sum_{j=N,W} \omega_j \hat{\upsilon}_{ijt} + \epsilon^{'}_{it}, \tag{1.8}$$

$$\tilde{y}^{\star}_{it} = \sum_{j=N,W} \kappa_j Price_{ijt} + \xi_k X_{it} + \xi_m Z_{ijt} + \sum_{j=N,W} \theta_j \hat{\upsilon}_{ijt} + \tilde{\epsilon}^{'}_{it}, \tag{1.9}$$

where $Z^{'}_{ijt}$ is an $(m+2) \times 1$ matrix which includes Z_{ijt} and two exclusion restrictions (*Telecommunications Wages*, *Mobile Penetration*).[36] Here $\beta_j, \omega_j, \kappa_j, \theta_j$, $j = N, W$ are

[36] Our exclusion restrictions seek to capture observable variables that may drive prices but which are not drawn from the demand side. Accordingly, we draw upon measures designed to capture cost variations (and hence indirectly prices) including a measure of telecommunications wages that varies by state and year and a measure of the density of mobile penetration by Economic Area which also varies by year.

parameters to be estimated, and τ_k, τ_m, γ_k, γ_m, ξ_k and ξ_m are vectors of parameters to be estimated. We assume that both $(X_{it},\, Z^{'}_{ijt},\, \epsilon^{'}_{it},\, v_{ijt})$ and $(X_{it},\, Z^{'}_{ijt},\, \tilde{\epsilon}^{'}_{it},\, v_{ijt})$ are i.i.d; $(v_{ijt},\, \epsilon^{'}_{it})$ and $(v_{ijt},\, \tilde{\epsilon}^{'}_{it})$ conditional on X_{it} and $Z^{'}_{ijt}$ have joint normal distributions with mean zero and finite positive definite covariance matrices.

In this case

$$y_{it} = \begin{cases} 1, & \text{if } \; y^{\star}_{it} > c, \\ 0, & \text{otherwise}, \end{cases} \tag{1.10}$$

and

$$\tilde{y}_{it} = \begin{cases} 1, & \text{if } \; \tilde{y_{it}}^{\star} > \tilde{c}, \\ 0, & \text{otherwise}, \end{cases} \tag{1.11}$$

where c and $\tilde{c}$ represent critical cutoff values that trigger household decisions to subscribe to wireline or wireless service, respectively.

For the bivariate probit model we allow correlation between $\epsilon^{'}_{it}$ and $\tilde{\epsilon}^{'}_{it}$ in the second step. That is,

$$\begin{pmatrix} \epsilon^{'}_{it} \\ \tilde{\epsilon}^{'}_{it} \end{pmatrix} |Price_{ijt}, X_{it}, Z^{'}_{ijt} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}\right], \tag{1.12}$$

where ρ captures the correlation in the errors across equations (13) and (14). The resulting estimates are consistent and asymptotically normally distributed. Our asymptotic covariance matrix of the 2SCML estimator is based on Rivers and Vuong (1988).[37]

After incorporating the interdependence of the wireline and wireless service subscription choice and accounting for endogeneity, the bivariate probit model performs quite well as shown in Table 3, Model (b). A comparison of the portfolio choices predicted by the model and those actually chosen indicates a good fit. The model correctly predicts 68 and 97 percent of households' portfolio decisions in the wireline and wireless equations, respectively. The specific parameter estimates also provide insight into the determinants of households' portfolio choices for telephony service. The nodal variables provide strong support for the concepts advanced in Section 2 above. In particular, households that are more closely attached to their domicile (node) are more likely to subscribe to wireline service and less likely to subscribe to wireless service. For example, households with a retired household member are significantly more likely to subscribe to wireline service and significantly less likely to subscribe to a wireless service. Other age-related variables that characterize household members (e.g., *Young Household* and *Young-Middle Household*) similarly reflect the greater propensity of younger and more mobile households to subscribe to wireless service, and the corresponding decrease in the propensity of these households to subscribe to wireline telephone service.

Households with different levels of work-related attachments are found to be attracted differentially to wireline and wireless services. In particular, *Ratio Working* increases the propensity to subscribe to wireless telephony and decreases the propen-

[37]See, in particular, Rivers and Vuong (1988) equations 4.7 and 4.11. Matrices incompatibility prohibits computation of the covariance matrix for recursive bivariate probit model, discussed below, which includes an additional explanatory variable. Nevertheless we provided estimation results from the second step and these are largely consistent with those obtained in the other estimations.

sity to subscribe to wireline telephony. Households in which a member works part-time (*Part-Time Employed*) are more likely to subscribe to both wireline and wireless service, in comparison to other households. Households with a self-reported *Housewife* appear more more likely to subscribe to wireline service and less likely to subscribe to wireless service, though these results are statistically insignificant.

Households with a health-limited youth (*Limited Youth*) are no different than other households in their propensity to subscribe to wireline service, but as anticipated are significantly more likely to subscribe to wireless service than other households. By contrast, households with a health-limited adult (*Limited Adult*) are more likely to subscribe to wireline services and less likely to subscribe to wireless services than other households. Households with students (*Student*) have significantly higher propensities to subscribe to wireless telephony and have significantly lower propensities to subscribe to wireline service. The estimations also reveal that, *ceteris paribus*, households in more rural areas have higher demands for wireless services in comparison to households in more urban areas. Finally, the estimations indicate that home ownership (*Own House*) is strongly associated with subscription to both wireline service and wireless service.

The price and income parameters are also revealing. Consistent with standard demand theory, *Wireline Price* and *Wireless Price* negatively [and statistically significantly *(p = .01)*] impact the demand for wireline and wireless service, respectively.[38]

[38] To account for the potential for heterogeneous responses of consumers across income and age categories, we alternatively included price interacted with income category and price interacted with age category. In some instances we found that younger people are less price-sensitive to the price of mobile service in the mobile equation. Estimates also provide modest indications that younger people are more price-sensitive with respect to the price of wireline service. We also find that lower income households are generally more price-sensitive than higher income households. Given the broad income and age categorizations, however, these results suffer from collinearity and are somewhat unstable. Accordingly, they are not reported here.

Beyond the own-price impact, however, the estimations also reveal that the cross-price effects are positive and highly statistically significant. Changes in the price of wireline service positively impact the demand for wireless service, while changes in the price of wireless services positively affect the propensity to subscribe to wireline service. The estimations indicate that consumers view wireline and wireless telephone subscriptions as substitutes. While the nonlinear nature of the estimations prevents simple interpretations of marginal effects (ME), they are estimable.[39] Specifically, recalling that $Q_n = \pi_N + \pi_{NW}$ and $Q_W = \pi_W + \pi_{NW}$, we estimate the marginal price effects $\frac{\partial Q_N}{\partial P_N}$, $\frac{\partial Q_W}{\partial P_W}$, $\frac{\partial Q_N}{\partial P_W}$ and $\frac{\partial Q_W}{\partial P_N}$. The results are presented in Table 4, and indicate that the own-service marginal effects are both negative and statistically significant *(p=.01)*, while the cross-partial derivatives are both positive and highly significant *(p=.01)*.[40] From equation (9), this latter result again indicates that wireline and wireless services display substitutable rather than complementary characteristics over the 2003-2010 period.

Table 4 indicates that *Income* is an important determinant to wireline and wireless subscription. In each case, income increments for those below the poverty threshold to higher levels increase subscription to both wireline and wireless services. The marginal effect of an income shift from the lowest to the highest category results in about a six percent increase in the likelihood of wireline service subscription *(p=.01)* and about a 26 percent increase in the likelihood of wireless service subscription *(p=.01)*.

[39] In nonlinear models with single-index form conditional means, marginal effects are calculated using the formula $ME_j = \frac{\partial \pi_j}{\partial x_j} \times \beta_j$. In our case, marginal effects are calculated at mean values of independent variables. For the bivariate probit model, we calculate marginal effects for the following probabilities: $\pi_N, \pi_W, \pi_{NW}, \pi_0, \pi_{W|N}, \pi_{N|W}, \pi_N + \pi_{NW}, \pi_W + \pi_{NW}$. (Cameron and Trivedi (2010)).

[40] Our estimates are conservatively based on the assumption that consumers respond to any price stimulus within a single period. To the extent that consumers fail to fully equilibrate within a single period (due, for example, to the multiyear nature of some wireless contracts) our estimates may be seen as a lower bound on the true marginal effects.

The quality and diffusion of wireless service are also found to affect consumers' telephony portfolio decisions. *Cellsites* is positive and highly significant *(p=.01)*, indicating as expected that quality improvements associated with greater coverage increases wireless telephony subscription. The *Cellsites* variable also captures the potential network effect of the impact of the increasing proliferation of the network on the likelihood that any household i will subscribe to wireless service.[41] Similarly, the diffusion of wireline broadband (*Wireline Broadband*) is seen to have enhanced the propensity to retain wireline telephone service and stem the move to wireless service. Finally, areas with more challenging topographies, such as mountains or large bodies of water, which reduce wireless service quality are found to reduce wireless subscription.

Among the most substantial changes in households' telephony portfolio over the 2003-2010 period, the shift away from "wireline-only" is arguably the most dramatic. As Figure 1 indicates, approximately 50 percent of all U.S. households subscribed exclusively to wireline telephony in 2003. That percentage had fallen to 12 percent by 2010. To explore this phenomena in more detail, we bifurcate the sample into an early period (2003-2006) and a later period (2007-2010).[42] Specifically, we decompose the aggregate marginal effects: $-\frac{\partial \pi_N}{\partial P_N} = \frac{\partial \pi_W}{\partial P_N} + \frac{\partial \pi_{NW}}{\partial P_N} + \frac{\partial \pi_0}{\partial P_N}$, permitting us to see how the marginal reaction of consumers to relative prices has evolved over time. Table 5 shows the decomposition results of the total marginal substitution effect associated with a change in the price of wireline service. In the 2003-2006 period, there is relatively moderate substitution directly away from wireline services. During

[41] The geographic scope of any network effect is difficult to bound conceptually. Accordingly, in an alternative estimation we employed a more narrow geographic measure of the potential for network effects by including a measure of the extent of wireless subscription in the county in which the household is located. This approach, which parrots Goolsbee and Klenow (2002), yields similar results to those reported here.

[42] We find similar patterns emerge if alternative years are chosen for this bifurcation.

this period, only about one-half of the marginal substitution from wireline-only customers was the result of households becoming wireless-only, with the other half seemingly trying out wireless telephony but not dropping their wireline service. By the 2007-2010 period, however, the marginal impact on wireline only households was largely toward a wireless-only portfolio choice. That is, the dominant marginal effect to any elevation of wireline prices in the later period was for households to "cut the cord" and go wireless-only.

1.3.2 Mixed Logit Model

To this point, we have permitted households' decisions to adopt wireless and wireline telephony to be related, but not part of a single household decision-making process. To allow for this possibility, we utilize a mixed logit model. This model accounts for heterogeneity in consumers' preferences and relaxes the assumption of the independence of error terms in the utility specification, unlike a multinomial logit model. In our model we allow the price coefficient to vary randomly across consumers. We specify the price coefficient to be independently normally distributed. We also account for potential endogeneity of the prices.

A consumer faces four alternatives for a telephone: (1) no phone, (2) wireline only, (3) wireless only, or (4) both wireline and wireless, and chooses the alternative with the highest level of utility. The utility of option j ($j = N, W, NW$), which accordingly corresponds to the choice of wireline only (N), wireless only (W), or both phones (NW) can be written as:

$$U_{ijt} = V(Price_{ijt}, X_{it}, Z_{ijt}, \beta_i) + \epsilon_{ijt}, \tag{1.13}$$

where all variables have the same notation as described above in the Bivariate Probit Model section, β_i is a random price coefficient that represents taste of consumer i, and ϵ_{ijt} is the unobserved portion of utility.

To address the issue of potential endogeneity of prices, we follow Petrin and Train (2010), implementing a control function approach. The idea behind the control function approach is to derive proxy variables that condition on the parts of endogenous variables that are correlated with the unobserved utility ϵ_{ijt}. This approach can be implemented if the endogenous variables are regressed on all the exogenous variables that enter utility and some variables Y that do not directly enter utility, but which do impact the endogenous variables (these variables are called exclusion restrictions).

The control function approach is conducted in two stages. In the first stage, OLS regression of prices (wireline and wireless) on the exogenous explanatory variables and exclusion restrictions is implemented:

$$Price_{ijt} = f(X_{it}, Z'_{ijt}, Y_{ijt}) + v_{ijt}. \tag{1.14}$$

Then we recover the estimated residuals to use them as control functions in the estimation of mixed logit in the second stage.

$$\epsilon_{ijt} = CF(v_{ijt}; \lambda) + \tilde{\epsilon}_{ijt}, \tag{1.15}$$

where λ is the corresponding 3×1 vector of parameter of the control function. We specify the control function (CF) as linear in v_{ijt}; $\tilde{\epsilon}_{njt}$ are i.i.d. extreme value and independent of other regressors.

The utility function with the control function that generates the mixed logit model is specified as:

$$U_{ijt} = V(Price_{ijt}, X_{it}, Z_{ijt}, \beta_i) + \lambda v_{ijt} + \sigma\eta_{ij} + \tilde{\epsilon}_{ijt}, \tag{1.16}$$

where η_{ij} is i.i.d. standard normal. The model is a mixed logit, with mixing over the error components η_{ij} , whose standard deviation σ is estimated, as well as over the random elements of β_i.

Conditional of the CF, the probability that consumer i chooses alternative s is equal to

$$P_{is} = 1(U_{ist} > U_{ijt} \forall j \neq i) f(\beta_i, \tilde{\epsilon}_i)\phi(\eta_i) d\beta_i d\tilde{\epsilon}_i d\eta_i \tag{1.17}$$

Given that the error terms follow extreme value distribution, the mixed logit probability based on this utility is

$$P_{is} = \int \left(\frac{e^{V_{is}(v_i,\nu_i,\eta_i)}}{\sum_{j=1}^{4} e^{V_{ij}(v_i,\nu_i,\eta_i)}}\right)\phi(v_i)\phi(\nu_i)\phi(\eta_i) dv_i d\nu_i d\eta_i. \tag{1.18}$$

Table 6 provides the results of the Mixed Logit model, which are similar to those provided in the Bivariate Probit estimation of Table 3. The importance of both the household's nodal propensities as well as price and income are confirmed. The price that households face for their respective portfolio choice is negative and highly statistically significant, indicating that consumers are price sensitive across the various options as they consider their portfolio of telephone services. Consumers from the lowest income category are the most price sensitive. Similarly, the nodal variable parameter estimates from the Mixed Logit model are quite similar in nature to those generated in the Bivariate Probit model, providing reassuring robustness.

1.4 Discussion

The introduction of new products or services with new technologies and characteristics presents a number of challenges to traditional demand analysis. Faced with this situation, consumers may replace or augment their existing consumption portfolios. In particular, the new product or service may serve as either a substitute or complement to the existing product or service. In this regard, the advent and diffusion of wireless telecommunications has radically altered traditional consumption patterns among consumers, creating a natural opportunity to consider telecommunications demand with a portfolio choice lens.

In this paper, we develop an economic framework capable of capturing the pattern and evolution of telecommunications consumers' portfolio consumption choices. In doing so, we provide several contributions that may serve as a platform for subsequent research. First, we formulate a portfolio choice framework for how households satisfy their communications needs. Second, within that portfolio choice model, we develop a theory of why (non-price) characteristics of households, especially related to their "nodal" versus mobile tendencies, affect their subsequent telephony portfolio choices. Third, the portfolio choice framework sheds considerable light on the "substitutes versus complements" issue that underpins competition and regulatory policies toward the telecommunications industry. Fourth, given our data window from 2003-2010, we are able to observe empirically how variations in the quality and ubiquity of the "new service" affects consumers' portfolio choices.

The empirical results provide considerable support for the approach that we have adopted. In particular, we find that variations in households' nodal characteristics serve as important drivers their portfolio choices of telephone service. Households that are more closely attached to their domiciles are more attracted toward wireline service, while households with more mobile lifestyles are more attracted to wireless telephony. The results also consistently and robustly reveal that wireline and wireless services have increasingly become substitutes. Variations in the quality and ubiquity of wireless telephony are found to be important determinants of wireless telephony subscription growth relative to wireline telephony over the 2003-2010 period.

Finally, our results may prove useful in a policy domain. At the most general level, our approach here may be seen as a platform for tracking the evolution of consumer responses to the emergence of new technologies. Understanding such responsiveness is crucial in the design of regulatory and competition policies. And, specifically, in its considerations of the appropriate level of regulation for wireline telephone services, the Federal Communications Commission has indicated that the issue of access substitution between wireline and wireless services is "critical" and a "difficult question."[43] While our study is generally directed at the more basic questions of the economic drivers of households' telephony portfolio choices, our results provide clear and robust indications of the access substitutability of wireline and wireless services. This substitutability indicates that regulatory policies designed that silo wireline and wireless services are no longer apt.

While advancing our understanding of households' portfolio choices, our research points toward next steps that hold the potential to paint a more complete picture of economic outcomes in the telecommunications industry. For example, our focus

[43]See Memorandum and Order, In the Matter of Petition of Qwest Corporation for Forbearance Pursuant to 47 U.S.C. Section 160(c) in the Phoenix Metropolitan Area, WC Docket No. 09-135, Federal Communications Commission, p. 30.

has been on the demand side of the evolving industry. By specifying and estimating a stylized supply-side model it may be possible to extend our results in several ways. For instance, with an appropriate specification of the supply side both the social welfare effects of the adoption of wireless services and the atrophying traditional fixed-line services could be evaluated. Also, by using knowledge of the cost structure it may be possible to conduct counter-factual simulations that could include, for instance, an examination of what pricing in wireline/wireless services would be in the absence of the other service. Additionally, such a more complete model would permit an identification of optimal pricing as done by Gentzkow (2007) in the provision of online and print newspapers. Our analysis here has also abstracted from a salient feature of the market for wireless telephony services; namely the durability of the hardware and consumer switching costs associated with early termination of wireless contacts. This suggests that subsequent research that considers intertemporal optimization in individual consumer decisions may provide substantial additional insights not afforded by our approach.

Chapter 2

Universal Service in a Wireless World

The goal of universal service has been central to telecommunications policy for over 100 years.[1] Over that period, policymakers have focused on a variety of metrics for judging the "universality" of service, but the most common has been the so-called "penetration rate" of landline telephone service among American households.[2] Universal service policies have been implemented to ensure that all Americans have the opportunities and security that telephone service provides, including opportunities for job search, being able to connect to family and emergency services.

It was against this backdrop that, in 1984 the Federal Communications Commission implemented the Lifeline program. The Lifeline program is a means-tested program that provides low-income households with a discount on their monthly telephone bill. Between 1988 and 2013 the number of Lifeline beneficiaries has grown from roughly 1.8 million to more than 13.3 million. The corresponding expenditures

[1]This effort first began through private-sector calls for "universal service" (see Parsons and Bixby (2010)) but later became an explicit public policy objective. See 47 U.S.C. § 151, stating that "communication by wire and radio so as to make available, so far as possible, to all the people of the United States, without discrimination...with adequate facilities at reasonable charges." Subsequently in Section 254 (b)(3) of the Telecommunications Act of 1996, the goal was made even more explicit, stating that "consumers in all regions, including low-income consumers...should have access to telecommunications and information services."

[2]The Communications Act of 1996 expanded the notion of universal service to include advanced telecommunications services as they evolve. In particular, in 2005, the universal services policies were extended to include wireless service; in 2010 the FCC released the National Broadband Plan that started to shape policies toward promotion of the high-speed Internet access.

of the program have grown from approximately 32 million dollars in 1988 to 1.4 billion dollars in 2013. Economic research on the Lifeline program has indicated that it has promoted telephone subscriptions, but the gains have been costly.[3]

While attracting 13.3 million beneficiaries, the Lifeline program has not historically proven to be attractive among poor households. Specifically, until 2008, only 30 percent of eligible households participated in the program as shown in Figure 7.[4]

At the same time that the Lifeline program was launching, an alternative means for individuals to telephonically communicate was commercially introduced. In 1983, Ameritech introduced the first cellular telephone service. Over the next 20 years, wireless communications became wildly successful. Today there are nearly 326 million wireless subscribers in the United States.

In recognition of the mobile telephony alternative to landline telephone service and also in recognition of the low "take-rates" of Lifeline among eligible households, the FCC made an important policy change in 2005. Specifically, while the Lifeline subsidies had historically only been available to wireline subscribers, the FCC lifted this restriction, allowing companies offering prepaid wireless services the opportunity to offer Lifeline service to eligible households.

In the wake of this new policy, Lifeline subscriptions and the costs of Lifeline grew rapidly. These ballooning costs of the Lifeline program provoked considerable

[3]Erickson, Kaseman and Mayo (1998) estimate that the cost per new subscriber was between $133 and $556 depending on the poverty level for the 1985-1993 period. Garbacz and Thompson (2002) show that the cost per added household was $191 in 1990, and it increased to $1581 in 1998. The most recent study by Ackerberg et al. (2013) estimates that the cost of adding a new subscriber was $519 in 2000.

[4]Burton, Macher and Mayo (2007) also document low Lifeline participation rates, and dramatic differences in state-level subscriptions. According to their statistics, in 2003 twenty-five states had participation rates of fewer than 10 percent of eligible households. Twelve states had participation rates between 10 and 20 percent. Only three states had participation rates more than 50 percent, with the highest participation rate in California - almost 70 percent.

criticism of the program, calls for program reform, and even proposed legislation to end the Lifeline program altogether or at least eliminate its wireless part.[5]

The merits of this policy change, hereinafter referred to as the *wireless Lifeline initiative*, to include not only wireline but also wireless telephony in the Lifeline program, has not undergone a systematic economic analysis. Specifically, while some observers have defended the Lifeline program noting that under the program the telephone penetration rate among low-income households increased from 80 percent in 1984 to 92.6 percent by 2013[6], this growth in subscribership may have been driven by factors other than the Lifeline program. Neither the posturing of critics or supporters of the Lifeline program provide specific insights on several key economic questions surrounding the program. Principal among these is whether the Lifeline program, as it has evolved has acted to promote connectivity of American households, and at what cost.

In this paper, I seek to provide further insights into the effects of the Lifeline program on household adoption of telephone service. I distinguish between two channels through which the subsidy may have impact: the levels of benefits and the regulatory change, specifically, the beginning of the subsidization of prepaid wireless service. The theoretical framework is a utility-based model of consumer behavior that incorporates characteristics suggested by the data, controls for the levels of subsidy benefits and regulatory changes. To address the potential endogeneity of prices and subsidy payments, I follow Petrin and Train (2010) and incorporate the control function approach.

[5]See, e.g., Spencer E. Ante "Millions Improperly Claimed U.S. Phone Subsidies," *Washington Post*, February 11, 2013, p. A1. Also see, the bill "Stop Taxpayer Funded Cell Phones Act of 2011" introduced by Rep. Tim Griffin; and "Ending Mobile Phone Welfare Act of 2013" introduced by Rep. David Vitter.

[6]See, FCC Monitoring Report, 2013.

The estimation relies on a unique database that combines both public and proprietary household-level data taken from the National Health Interview Survey (NHIS).

The data consists of telephone choices of the surveyed households, their demographic characteristics, prices of telephone services, quality characteristics of wireless service, subsidy benefits, and controls of availability of subsidies for wireless prepaid service in each state in the United States for the 2003-2010 period. The econometric specification is a random-utility discrete-choice model. A virtue of using a structural econometric framework in this case is that a range of experiments can be performed using the estimated demand system. The experiments include abolishing of subsidies for wireless service, and elimination of subsidies for telephone services altogether.

The results indicate that the higher the amount of subsidy received by a household, the greater the propensity of the household to subscribe to a telephone service. If the subsidies for wireline and wireless services were to be cancelled, my model predicts that more than one million households would give up the telephone service. Given that the Lifeline payments in 2010 accounted for approximately $1.2 billion, the estimated cost of adding a new subscriber is $1,151 per year. The actual average cost of the subsidy per household is $138 per year. That means that only one out of eight households that are enrolled in Lifeline is subscribed to telephone service because of the subsidy. The other seven would have a phone in the absence of the subsidies. The results reveal that the adoption of the wireless Lifeline initiative has a positive impact on the propensity of households to subscribe to the telephone service, however it is quite costly. My model predicts that if the wireless part of Lifeline were to be eliminated, 147,034 households would cancel telephone service. Given that the total amount of Lifeline payments to prepaid wireless carriers was around $416 million in 2010, the estimated cost per new subscriber is $2,835 per year. That means that only one out of twenty households that receive subsidies for wireless prepaid service subscribes to the telephone service because of the subsidy. The other nineteen are infra-marginal subscribers.

The empirical literature on the subsidization of telephone services focuses mainly on traditional wireline service. Studies by Garbacz and Thompson(1997, 2002, and 2003), Eriksson, Kaserman and Mayo (1998) and Ackerberg et al. (2013) investigate the impact of Lifeline and Link Up on the penetration of local *landline* telephone service. The first two studies examine a broad population sample and find that low-income subsidies have increased penetration rates, although the quantitative effect appears to be small relative to the cost of these programs. Ackerberg et al. (2013) restrict their analysis to the sample of eligible households instead of using a sample of the whole population. Their results reveal a significant impact of the subsidies. Their estimates show that Lifeline and Link Up increased penetration rates by 6.1 percent among eligible households.

My paper builds on the literature that studies telecommunications demand. To date, the bulk of this literature focuses on the wireline network alone. Studies by Perl (1983), Taylor and Kridel (1990), Bell Canada (Bodnar et al. 1988), Train, McFadden and Ben-Akiva (1987), Schement (1995), Riordan (2002) investigate the effects of price of access, income and a wide range of socio-demographic characteristics on the probability of a household having a phone. Studies of Rodini, Ward and Woroch (2002), Gideon and Gabel (2011), and Macher et al. (2012) expand the communication options for a household and account for the option to subscribe to wireless service.

This study contributes to the existing literature in several ways. I utilize a unique micro-level data set, which allows analysis of the telephone subscription decision on a granular level. My framework accounts for the possibility of a household to subscribe to wireline or wireless services, whereas the majority of studies investigating the impact of telephone subsidies included only traditional landline service. I explore how the extension of Lifeline to include wireless service affected the propensity of a household to adopt a phone. To my knowledge, there has been no empirical study of this regulatory change.

The paper proceeds as follows. The next section describes the evolution of universal service policies. Section 3 provides a description of the econometric specification. Section 4 describes data and gives summary statistics. Section 5 contains estimation results, and Section 6 concludes.

2.1 Evolution of Universal Service Policies

The notion of universal service first appeared in AT&T President Theodore Vail's speech in 1907, in which he advocated for "one system, one policy, universal service." Universal service as an official national policy was first expressed in the Communications Act of 1934 that established a national goal "to make available, so far as possible, to all people of the United States,... a rapid, efficient, Nation-wide, and world-wide wire and radio communication service with adequate facilities at reasonable charges."[7] Between 1934 and 1984, efforts to promote universal service were implicit, with regulators keeping local exchange service rates at artificially low levels. Local exchange service was funded through a system of cross-subsidies from long-distance services to local services, from business customers to residential customers, and from urban areas to rural areas.[8]

After the divestiture of AT&T in 1984, the Federal Communications Commission (FCC) implemented two principal mechanisms to promote universal service. First,

[7]Communications Act of 1934, 47 U.S.C. § 151.

[8]See Kaserman, Mayo and Flynn (1990), and Kaserman and Mayo (1994).

the High Cost Fund, an untargeted subsidy program,[9] provided a subsidy to telephone companies that experienced costs in excess of a federally established threshold. Second, the FCC implemented two programs that provided subsidies to low-income households that were considered at risk of not subscribing to telephone service in the absence of a subsidy. The Lifeline program was established in 1984, and the Link Up program was established in 1987. Lifeline provides a recurring monthly subsidy for telephone service to qualifying low-income households. Link Up is a one time subsidy that reduces the initial subscription fee to the public switched network or the activation fee to wireless service.[10] Link Up has been a much smaller program than Lifeline, it accounted for less than 10 percent of total subsidy payments. It was eliminated except to recipients on Tribal lands in February 2012 as a result of FCC reforms,[11] and it is not addressed in the current study.

All universal service support mechanisms, including Lifeline, are funded by the Universal Service Fund (USF). The USF is collected via contributions of telecommunications carriers. Companies pay a percentage (or contribution factor) of their interstate and international end-user revenues into the USF. Telecommunications companies recover the contribution fees through charges to end-users. For instance, all customers of Verizon as a part of their bill pay Federal Universal Service Charge (FUSC) and if applicable a State Universal Service Charge (SUSC). Carriers that provide Lifeline receive universal support reimbursement for each qualifying low-income consumer served.

[9] In this context, "untargeted" means that subsidies are not provided to individual consumers. Instead, telephone companies receive federal support.

[10] Eriksson, Kaserman and Mayo (1998) provide a study of the effectiveness of the untargeted and targeted subsidy mechanisms in promoting household subscribership. They find that targeted subsidy programs are considerably more effective than untargeted subsidies in promoting the goal of universal telephone service.

[11] See, FCC "Report and Order and Further Notice of Proposed Rulemaking" released on February 6, 2012.

In 2012 the average amount of Lifeline support to non-Tribal subscribers was $9.32 per month ($112 per year) for telephone charges. Table 7 shows the amount of Lifeline subsidy in every state in 2011.

While the Lifeline program was initially established as a relatively small federal program, benefits were expanded and incentives in the form of federal matching funds to the states were added in 1998. This was done to encourage the establishment of state-level Lifeline programs to raise the available subsidies.[12] Individual states that established their own Lifeline programs to complement available federal funds were provided the latitude to establish their own state-specific eligibility criteria.[13] The result of this policy change was that subsidy levels expanded significantly from $148 million in 1987 to $422 million in 1998.

Following the 1996 Act, the FCC took several steps to increase participation in the Lifeline program. First, in 2000 it enhanced the program benefits for residents living on or near federally-recognized tribal lands and reservations. In 2004, the Commission sought to increase participation by expanding the federal default eligibility to include an income-based criterion of 135 percent of the federal poverty guidelines and additional means tested programs.[14]

By 2003, the number of Lifeline participants reached almost 6.5 million, and payments increased to more than $685 million. Despite the growth in the number of Lifeline subscribers, policymakers began to observe that participation levels among

[12] See Federal Communications Commission (2004b), Table 19.8, note 1.

[13] If the state does not have its own Lifeline program, then consumers must satisfy the federal eligibility criteria to enroll in Lifeline; specifically, that they have income at or below 135 percent of the Federal Poverty Guidelines, or that they participate in one of the seven federal low-income programs: Medicaid, Supplemental Nutrition Assistance Program (SNAP), Supplemental Security Income (SSI), Federal Public Housing Assistance, the Low-Income Home Energy Assistance Program, the National School Lunch Program, or Temporary Assistance for Needy Families (TANF).

[14] See *Lifeline* and *Link Up*, Report and Order and Further Notice of Proposed Rulemaking, 19 FCC Rcd 8302 (2004).

eligible households were quite low. As depicted in Figure 1, in 2003, only one third of eligible households subscribed to the program. This low take rate compared unfavorably with the participation rates for other means-tested social programs. For instance, the estimated participation rate in Medicaid was 52 percent in 2002,[15] and the estimated participation rate in the Supplemental Nutrition Assistance Program (SNAP) was 56 percent in 2003.[16]

In 2005, the FCC implemented "Lifeline Across America" a public awareness program to increase participation in the Lifeline program. The ÒLifeline Across America program included developing guidelines to help carriers target eligible consumers for participation, producing joint outreach materials in both English and Spanish, and initiating a "Train-the-Trainer" program designed to educate state and local government officials about Lifeline and Link Up eligibility requirements and procedures. Perhaps as a result, the participation rates slightly increased in 2005 as shown in Figure 1.

Also in 2005, the FCC decided to forego a Òfacilities requirementÓ for approving telephone companies as Eligible Telecommunications Carriers (ETCs) for Lifeline support only. Since the 1996 Telecommunications Act the FCC had maintained a requirement that only facilities-based telephone companies could serve as ETCs for the purpose of receiving support to offer Lifeline service. Based on the petition of TracFone, a non-facilities-based, commercial mobile radio services provider (reseller) offering prepaid service, however, the FCC decided to eliminate the facilities requirement. This decision paved the way for wireless prepaid carriers[17] to begin to offer Lifeline service as part of their commercial activities. The Commission argued that

[15] See, Davidoff et al. (2005).

[16] See, "Reaching Those in Need: State Food Stamp Participation Rates in 2003" by USDA.

[17] "Prepaid wireless service is any wireless telecommunications service that is activated in advance by payment for a finite dollar amount of service or for a finite number of minutes that terminate either upon use by any person or within a certain period of time following

adoption of the wireless Lifeline initiative would create a number of benefits including increases in consumer choice and program participation.

Although TracFone was granted a forbearance from the facilities requirement in 2005, its designation as an ETC was conditional on implementation of several other FCC requirements. In 2008 TracFone became the first carrier offering prepaid wireless service to be designated as an ETC.[18] The first Lifeline offerings by wireless prepaid carriers began in 2008. By 2010, 46 states had certified wireless carriers as an ETC eligible to receive Lifeline benefits.[19]

In fact, facilities-based wireless carriers had provided Lifeline support before 2008; however, the Lifeline wireless payments were negligible. The elimination of the "facilities requirement" opened a way for many resellers that previously had not qualified as ETCs, to apply for provision of Lifeline support. For this reason, the wireless Lifeline initiative is often referred to as the beginning of subsidized wireless phones, popularly called "Obama phones."[20]

Figure 8 shows that the number of Lifeline participants has been growing significantly since 2008, from approximately 6.7 million in 2008 to more than 17.1 million in 2011. Figure 9 shows that as a result, the payouts under the program have grown from $822 million in 2008 to almost $2.2 billion in 2012.

This increase in the number of households participating in the Lifeline program resulted in an increase in *participation rates* beginning in 2008. Figure 4 depicts that from 2003 to 2008 the participation rate remained fairly constant, about 30 percent. After 2008, the take rates took off and reached around 55 percent in 2011. To better

the initial purchase or activation, unless an additional payment is made." U.S. Government Accountability Office (2010), p. 2

[18]See "TracFone Wireless, Inc. ETC Designation," FCC, April 2008.

[19]Government Accountability Office (GAO) (2010), e-supplement survey, question 5.

[20]This moniker is however inapt. The change in the regulation was approved in 2005, during the Bush Administration.

understand the nature of this increase in participation rates, I segmented Lifeline participants into subscribers to wireline, wireless excluding prepaid, and prepaid wireless services. Figures 7 and 8 show that most of the growth since 2008 in the number of program subscribers and payments occurred due to the growth of Lifeline subscribers to prepaid wireless service.

Note that concurrent with the effective implementation of the wireless Lifeline initiative in 2008, the country entered a period of significant financial turmoil and recession, during which other social welfare programs also experienced significant increases in the number of participants in these programs and program costs (see Figure 9). Potentially, the growth of Lifeline may be caused by the wireless Lifeline initiative, or by the worsened economic conditions and decreases in income.

The liberalization of Lifeline, i.e. introduction of subsidies for prepaid wireless service, might have caused a shift in eligible consumers, who did not participate in the subsidy program before the reform, to Lifeline. These could be either customers who were not subscribed before the liberalization (marginal consumers), or customers who would have subscribed to telephone service anyway, but who now find it more attractive to take Lifeline (infra-marginal subscribers).

A second source of change that might be caused by the wireless Lifeline initiative is that the filter by which households are deemed to be eligible becomes less binding. After the regulatory shift, some households that would have been declared non-eligible may now successfully sign up for Lifeline should they wish to even though they are technically not eligible.

In fact, the wireless Lifeline initiative provoked a less restrictive process of enrollment and some of the non-eligible households were able to receive the subsidy. The program, initially designed for traditional wireline service, was not adjusted for extension to wireless service which is quite different in nature. This led to fraud and waste of federal funds.[21] Based on the ETCs' surveys conducted in 2011, 9 percent of the respondents surveyed responded that they were no longer eligible for Lifeline, and 27 percent of subscribers failed to respond to the carriers' verification surveys. The verification procedures during initial enrollment in the program have also proved inefficient in some states. Lifeline subscribership data reflects troubling evidence suggesting that non-eligible households may be enrolling in the program at a particularly rapid rate in states that do not require documentation of program-based eligibility at sign-up. For example, the number of Lifeline subscribers in Louisiana, which does not require documentation of program participation at enrollment, increased by 1,565 percent from 2008 to 2011. Over the same period, the number of Lifeline subscribers in Kansas, which does require documentation, increased only by 105 percent from 2008 to 2011.[22]

Taking into account the possibility of ineffective enforcement of the program rules, I estimate my model in two scenarios. First, when only eligible consumers are able to enroll in the low-income program (perfect enforcement). Second, when there is lack of enforcement and any household is able to subscribe to Lifeline (ineffective enforcement). I estimate the impact of the subsidy on telephone adoption rates and the effect of the wireless Lifeline initiative in these two settings.

2.2 Econometric Specification

In my scenario, a consumer faces four alternatives for a telephone: (1) no phone, (2) landline only, (3) cell phone only, or (4) both landline and cell phone. A consumer chooses the alternative with the highest level of utility. To estimate this random utility model, I utilize a mixed logit model. This allows me to account for heterogeneity in

[21] Julie A. Veach (2013).

[22] See, FCC "Report and Order and Further Notice of Proposed Rulemaking" released on February 6, 2012.

consumers' preferences, and relaxes the assumption of the independence of error terms in the utility specification, unlike a multinomial logit model. A mixed logit generalizes a standard logit model by allowing the parameter associated with an observed variable (e.g. its coefficient) to vary randomly across customers. Variance in the unobserved customer-specific parameters induces correlation over alternatives in the stochastic portion of utility. The lack of correlation in utility over alternatives gives rise to the independence of irrelevant alternatives (IIA) property and its restrictive substitution patterns.

In the mixed logit model, the price coefficient varies across consumers, while other coefficients are fixed. I specify the price coefficient to be independently normally distributed. I also account for potential endogeneity of the prices and levels of subsidy benefits.

The utility of option j ($j = N, W, NW$), which accordingly corresponds to the choice of wireline only (N), wireless only (W), or both phones (NW) can be written as:

$$U_{njt} = V(Price_{njt}, LL_{nt}, WLI_{njt}, \mathbf{X}_{nt}, \beta_n) + \epsilon_{njt}, \tag{2.1}$$

where $Price_{njt}$ is the price of service j ($j = N, W, NW$) faced by household n at time t; LL_{nt} denotes the amount of Lifeline benefits that household n faces at time t; WLI_{njt} represents the wireless Lifeline initiative (it is approximated by the total amount of subsidy payments to wireless prepaid ETCs in the state of household n's residence at time t); $\mathbf{X}_{nt}$ is a $k \times 1$ vector that includes all other controls, such as income and demographic characteristics of household n at time t and some alternative-specific characteristics in the area where household n resides; β_n is a random price coefficient that represents taste of consumer n; ϵ_{njt} is the unobserved portion of utility.

To address the issue of potential endogeneity of prices and low-income benefits, I follow Petrin and Train (2010), implementing a control function approach. The idea behind the control function approach is to derive proxy variables that condition on the parts of endogenous variables that are correlated with the unobserved utility ϵ_{njt}. This can be done, if endogenous variables are regressed on all the exogenous variables that enter utility and some variables Z_n that do not directly enter utility, but do impact endogenous variables (these variables are called exclusion restrictions). In other words:

$$\begin{cases} Price_{njt} = f(\mathbf{X}_{nt}, Z_{nt}) + \upsilon_{njt}, \\ LL_{nt} = f(\mathbf{X}_{it}, Z_{nt}) + \nu_{nt}. \end{cases} \tag{2.2}$$

In my estimation, I run simple OLS regression of prices and subsidy benefits on $\mathbf{X}_{nt}$ and Z_{nt}, and recover the estimated residuals to use them as control functions in the estimation of mixed logit.

$$\epsilon_{njt} = CF(\upsilon_{njt}, \nu_{nt}; \lambda_P, \lambda_B) + \tilde{\epsilon}_{njt}, \tag{2.3}$$

where $CF(\upsilon_{njt}, \nu_{nt}; \lambda_P, \lambda_B)$ denotes the control function with corresponding parameters λ_P and λ_B. I specify the control function as linear in υ_{njt} and ν_{nt}; $\tilde{\epsilon}_{njt}$ are i.i.d. extreme value and independent of other regressors. The utility function with the control function that generates the mixed logit model is specified as:

$$U_{njt} = V(Price_{njt}, LL_{nt}, WLI_{njt}, \mathbf{X}_{nt}, \beta_n) + \lambda_P \upsilon_{njt} + \lambda_B \nu_{nt} + \sigma\eta_{nj} + \tilde{\epsilon}_{njt}, \quad (2.4)$$

where η_{nj} is i.i.d. standard normal. The model is a mixed logit, with mixing over the error components η_{nj} , whose standard deviation σ is estimated, as well as over the random elements of β_n.

Conditional of the CF, the probability that consumer n chooses alternative i is equal to

$$P_{ni} = \int \mathbb{1}(U_{nit} > U_{njt} \forall j \neq i) f(\beta_n, \tilde{\epsilon}_n)\phi(\eta_n) d\beta_n d\tilde{\epsilon}_n d\eta_n \quad (2.5)$$

Given that the error terms follow extreme value distribution, the mixed logit probability based on this utility is

$$P_{ni} = \int \left(\frac{e^{V_{ni}(\upsilon_n, \nu_n, \eta_n)}}{\sum_{j=1}^{4} e^{V_{nj}(\upsilon_n, \nu_n, \eta_n)}}\right)\phi(\upsilon_n)\phi(\nu_n)\phi(\eta_n) d\upsilon_n d\nu_n d\eta_n. \quad (2.6)$$

I estimate my model in two settings: perfect enforcement of eligibility of subsidies, and ineffective enforcement, when non-eligible households are able to enroll in the low-income program. The data do not permit identification of households that are enrolled in Lifeline; therefore, I need to impose assumptions on who are potential subsidy beneficiaries. However, I am able to identify households that satisfy the federal eligibility criteria to receive subsidies.

In the framework of perfect enforcement, the subsidy levels as well as the expansion of Lifeline are relevant only to eligible households. To account for that, the amounts of the Lifeline benefits, and control for the wireless Lifeline initiative enter utility function intersected with the dummy variable indicating that a household is eligible to enroll in the program. In the framework of ineffective enforcement, I assume that any household is a potential beneficiary of Lifeline. In this case, subsidy levels and Lifeline expansion are relevant for every household and these variables enter utility without any intersection.[23]

2.3 Data

Data for this research is taken from the National Health Interview Survey (NHIS) conducted by the National Center for Health Statistics (NCHS). The NHIS is a cross-sectional household survey that collects data on roughly 35,000 - 40,000 households and 75,000 - 100,000 individuals annually. The survey does not follow the same individuals through the course of interviews, hence this is not a panel. The NHIS includes questions on demographics, the health status of the population, and telephone coverage. Specifically, the survey includes questions about the status of household subscription to telephone service: either wireline or wireless, both or none. The NHIS conducts the survey in person and covers the civilian and non-institutionalized population residing in the United States at the time of the interview.[24]

While most of the NHIS data are publicly available, specific household location is confidential. With the approval of the Center for Disease Control and Prevention (CDC), however, I obtained the restricted portion of the data and could therefore link the NHIS sample to data from the Federal Communications Commission (FCC), the United States Census Bureau, the United States Bureau of Labor Statistics, and the United States Department of Agriculture.

[23] This approach is used in the majority of existing studies of Lifeline (see, Garbacz and Thompson (1997, 2001, 2003)), except for the study by Ackerberg et al. (2013) who conduct analysis on the sample of low-income households.

[24] For further details see *http://www.cdc.gov/nchs/nhis/about_nhis.htm.*

2.3.1 Data Overview and Descriptive Statistics

The initial NHIS data set contains 190,072 household-level observations. I eliminate observations for which essential information is missing. The sample used in the estimation contains approximately 20,000 observations in each year for the 2003-2010 period, or 167,397 household-level observations in total. Table 8 shows the annual percent of households without phone service in the sample. It stays around 1.2 percent every year with small variation, and it does not diminish.[25]

Figure 10 shows the statistics for annual telephone subscription rates for the whole sample, including both eligible and low-income households. Low-income households are households with income below poverty level, and they are a subset of eligible households. As displayed in Figure 10, low-income households experience the lowest subscription rates, followed by eligible households. The overall subscription rate stays around 99 percent, and it slightly decreases after 2007.

Figures 1, 11, and 2 show annual telephone subscription choices separately for the whole sample, eligible households, and low-income households accordingly for the period of 2003-2013. The telephone choices include no phone, landline only, wireless phone only, or both services. Both eligible and low-income households are more likely to choose subscription to only one service, and there has been a dramatic shift in preferences toward wireless service among all groups of households. In the period of 2003-2008, both eligible and low-income households exhibit heavy reliance on landline. In 2008, for the first time the percent of households who subscribed to cell phone for

[25]As shown in Table 8, the full NHIS sample contains larger percentage of households without telephone service; however for some households in the sample essential information is missing. In most cases, it is the information about income level that is not provided. However, as shown in Appendix A, demographic characteristics of the NHIS data set closely resemble those of the U.S. population. For this reason, I believe that the estimates based on restricted sample of households for which all information is represented are correct.

the whole sample exceeded the percentage with landline. The same shift occurred among eligible and low-income households in 2009.

Figures 11 and 2 show heavy reliance of low-income and eligible households on wireless service in recent years. In 2013, 52 percent of eligible households were wireless-only, and more than 57 of low-income households subscribed only to cell phone. In contrast, the sample average was around 42 percent in 2013.

It is correspondingly 10 and 15 percent higher than the sample average in 2013.

2.3.2 Variables

To determine the main factors that influence demand for telephone service, and in particular the effect of subsidies and regulation, I employ several groups of explanatory variables. Variables of primary interest are levels of subsidy and measures of changes in regulation. Second, I incorporate price measures along with household income. Third, I include demographic characteristics that have been historically shown to affect the demand for telephone service. Fourth, I control for quality characteristics of wireline and wireless services. Fifth, I account for the potential of a network effect associated with wireless telephony adoption. Below I provide a general overview of the variables. Appendix B includes the notation, definitions and sources of all variables.

Low-Income Program Variables To account for effect of the subsidies, I include combined federal and state monthly Lifeline support per beneficiary by state (*Lifeline Benefit*) for the 2003-2010 period. These data are available within the FCC "Universal Service Monitoring Report." I expect that higher program benefits will result in an increased propensity of telephone subscription.

From the NHIS data, I identify households eligible for low-income benefits according to the federal eligibility criteria (*Eligible Household*). A household is considered to be eligible for the low-income subsidy if its combined income is at or below 135 percent of Federal Poverty Guidelines,[26] or if any of its members participates in one of seven federal low-income programs: Medicaid, Supplemental Nutrition Assistance Program (SNAP), Supplemental Security Income (SSI), Federal Public Housing Assistance, the Low-Income Home Energy Assistance Program, the National School Lunch Program, or Temporary Assistance for Needy Families (TANF).[27]

To control for the wireless Lifeline initiative in a particular state, I use total prepaid wireless Lifeline payments within the state for each year (*Wireless Lifeline Initiative*). TracFone, the first non-facilities-based wireless reseller to be granted an ETC designation, started providing Lifeline support in 2008, but only in three states - Florida, Tennessee and Virginia. In 2009, SafeLink Wireless, the brand under which TracFone advertises its Lifeline program, was present in 20 states; in 2010, SafeLink Wireless was already present in 31 states. Zero or very small amounts of payments under the wireless Lifeline initiative mean that there is no ETC in the state that offers Lifeline for wireless prepaid service, or that eligible customers are unaware of the subsidies. The bigger is the amount of payments under the wireless Lifeline initiative,

[26]In the NHIS data set income is reported in groups according to the ratio to the poverty level. For this reason, I am not able to identify households with an income at or below 135 percent to the poverty threshold. Instead, the data permits authentication of households at or below 124 percent of the poverty level. I use this income category to identify eligible households.

[27]The NHIS data set does not have information on whether a household participates in Federal Public Housing Assistance, the Low-Income Home Energy Assistance Program, or the National School Lunch Program. Instead, it has a question about whether any family member receives income from any welfare program other than Medicaid, SNAP, SSI or TANF. I will use this variable as an approximation for participation in the three programs missing from the NHIS data.

the more likely that the subsidy for prepaid wireless service is easily available to eligible households in that particular state.[28]

Since low-income subscribers tend to rely on wireless service more, I expect the wireless Lifeline initiative to attract more low-income households to adopt telephone service.

Price and Income Variables In order to estimate consumer demand empirically, I include measures of wireline and wireless prices. I use 2002 data on the basic flat monthly charges by wire centers throughout the U.S.[29] The areas served by wire centers typically comprise parts of several counties. I use population weights within individual wire centers to construct a weighted price by county for residential landline service throughout the U.S. To update these data for the 2003-2010 period, I utilize the Federal Communication Commission's "Reference Book of Rates, Price Indices, and Household Expenditures for Telephone Service" (Reference Book). The Reference Book reports the results of an annual survey of local monthly fixed telephone rates for 95 cities located throughout the U.S. The year-to-year Pearson correlations between the prices are very high, averaging .96 during the relevant time period, indicating that the major source of wireline price variation is captured by the spatial disaggregation of prices at the beginning of the sample period. The prices are updated by the values

[28]For robustness check, I used other controls for the wireless Lifeline initiative, such as an indicator that subsidies for wireless prepaid service are offered in a particular state, and wireless Lifeline prepaid payments per capita. The regression results with either of these measures are very similar to the ones with the total prepaid wireless payments.

[29]These data were graciously provided by Greg Rosston, Scott Savage and Bradley Wimmer. See Rosston, Savage and Wimmer (2008) for their research using these data. While many local telephone companies offer local measured service in which customers pay a smaller monthly subscription charge and (after a call or minute allowance) pay a marginal charge per minute or call, industry sources report that the percentage of customers who avail themselves of this option is *de minimus*. Accordingly, I focus on consumers' choices based on variations in flat monthly rates. For a detailed study of the economics of such optional calling plans, see Miravete (2002).

of the Consumer Price Index (CPI) for local exchange service during the 2003-2010 sample period.

Finding a measure of wireless price is quite a challenge. Mobile carriers offer numerous subscription plans to consumers. A plan usually includes a "bucket" of minutes for a flat rate charge. For consumers whose usage levels remain within the purchased bucket, the price can be taken as an average monthly expenditure for the service. Data on average expenditure per user (including roaming charges and long-distance toll calling) were taken from the Cellular Telephone and Internet Association (CTIA). CTIA conducts a semi-annual survey of its member companies called *Wireless Industry Indices.* The survey includes data from companies representing over 95 percent of all U.S. wireless subscribers between 2003-2010. To account for spatial variation in the measure of wireless prices, I incorporate local and state taxes paid by consumers in different locales. Data on state and local taxes are provided by the Committee on State Taxation (COST). The tax data are collected every three years starting in 1998 (i.e. 2001, 2004, 2007 and 2010).[30] COST reports the prevailing state sales tax inclusive of general sales taxes. Local tax rates for each state were calculated as the average of those imposed in the largest city and those imposed in the capital city. The first two reports include the single measure of local and state taxes applied to wireline local and long distance service as well as mobile service. In later reports, taxes levied specifically on wireless service were reported separately. I used linear interpolation to calculate tax rates for the years between reports.

Drawing on the NHIS survey data, I also include measures of household income. Household income is categorized relative to an annual poverty threshold using four dichotomous variables. Household income below the poverty threshold (*Income1*), between one and two times the poverty threshold (*Income2*), between two and

[30]See COST (2002, 2005) and Mackey (2008, 2011).

four times the poverty threshold (*Income3*), and more than four times the poverty threshold (*Income4*) are relevant categories.

Endogenous Variables and Exclusion Restrictions I consider the potential endogeneity of prices and the amount of the Lifeline subsidy. The endogeneity of prices may rise for several reasons: for example, where there is an unobserved attribute of the service, such as quality or advertising, that is correlated with price. Without correcting for endogeneity, the aggregated demand is estimated to be upward-sloping, suggesting that omitted attributes are positively correlated with demand.

The endogeneity concern regarding the amount of Lifeline subsidy arises from the presumption that states with lower telephone subscription rates might provide higher low-income support in order to increase penetration rates. This assumption is supported by the statistics from the FCC Monitoring Report, 2012. Table 9 shows that in 1997 the penetration rates among low-income households in the states with high assistance is lower than in the states with intermediate or low assistance. The same holds for the sample of all households; however, the difference in penetration rates among states with different levels of assistance is smaller.

As always with endogeneity, the selection of exclusion restrictions is an issue. Exclusion restrictions should be correlated with the endogenous variables, but should not affect the dependent variable. The exclusion restriction I use in the equation (2) for estimation of the wireline price is the *Hausman-Type Instrument.*[31] This instrument seems to be appropriate, because carriers face the same regulations and fees within the same state, so the prices of the same carrier in other counties should reflect common costs within the state. The price instrument for county i is calculated as the average price in other counties in the same state.

[31]See Hausman (1996), Petrin and Train (2010).

To estimate the wireless price, I use *Mobile Penetration.* It is plausible that economies of scale exist in the wireless industry. Economies of scale imply cost reductions with increased penetration. Thus, mobile penetration might impact the price as a cost-shifter. Regression analysis shows that the mobile penetration rate does not influence telecommunications demand. Hence, it seems to be a reasonable choice of instrument.

I use the percent of families at or below 135 percent of the poverty level (*Families Below 135*) as the exclusion restriction for the subsidy payments. This variable does not directly affect the telecommunications demand, but states with higher poverty levels may be more prone to provide higher social benefits. To check for robustness, I also use the party affiliation of the governor (*Democrat Governor*) as an exclusion restriction for the amount of the subsidy. The Public Utility Commission plays a major role in determining the size of the Lifeline subsidy. In the majority of the states, a public utility commissioner is appointed by the governor; Democrats might be inclined to provide more generous subsidies than Republicans.

Demographic Variables I include demographic variables that are conventionally regarded as important determinants of telephone demand. I control for age (*Age of Head of Household*), education (*Educated Household*), household size (*Household Size*), home ownership (*Own Home*), ratio of employed members in a household (*Ratio Working*), number of children (*Children*), the presence of a student in a household (*Student*), the presence of members with health limitations (*Limited Youth* and *Limited Adult*) in a household, the presence of a retire in a household (*Retired Household*); racial composition (*White, Black, Hispanic* and *Native American Households*), and gender composition (*Female Household* and *Male Household*).

Quality Variables/Geographic Variables I include population density (*Population Density*) to account for potential network effects, or in contrast, the potential extra value of connection to a resident of a rural area.[32] To capture the increase in demand due to inter-temporal variation in the wireless service quality, I control for a number of cell sites deployed by the wireless industry in each year between 2003-2010 (*Cell Sites*).[33]

Mobile Network Effect Variable Network effects are often used as a rationale for telephone subsidies. However, some researches[34] argue that at high penetration rates, the marginal impact of network externalities is very low and any subsidy assistance is unlikely to have benefits comparable to costs. In order to capture the potential for mobile network effects, I include the penetration rate for mobile telephones within a given household's economic area (*Penetration Rate*).

2.4 Results

Table 10 identifies the telephone choices of households for the NHIS sample of 167,397 households used in the estimation. While the percent of households without telephone service has not been changing significantly over the sample period, households' choices of telephone options have changed substantially. The percentage of households with only a landline subscription has been diminishing over the years, while the percentage of households with only a wireless service subscription has been

[32]See, Macher et al. (2012).

[33]The annual data are available in the CTIA report. It includes repeaters and other cell-extending devices but excludes microwave hops. The location of the specific cell site is confidential, thus I am unable to account for their geographic distribution. My measure of cell sites might also underestimate inter-temporal wireless service quality improvement due to technological differences of towers deployed in the different periods.

[34]See Barnett and Kaserman (1998).

increasing during the 2003-2010 period. The percentage of households that subscribe to both wireline and wireless phones has been increasing since 2003, reaching a peak in 2007; after that the percentage has decreased. Table 11 provides summary statistics, average prices and subsidy benefits levels for the 2003-2010 period.

First, I estimate a mixed logit model in a perfect enforcement framework, in which I assume that only eligible households are able to enroll in the subsidy program. In each regression the unit of observation is a household and the dependent variable is the telephone choice of the household.

The independent variables of interest are the amounts of subsidy benefits (*Lifeline Benefit*), and the total amount of Lifeline payments for wireless prepaid service in a state (*Lifeline Wireless Initiative*). All subsidy-related variables enter the model intersected with *Eligible Household*.

I also control for the prices of all telephone options (wireline, wireless, or both services). The price of the outside option (no phone) is zero. I include controls for household income and demographic characteristics (*Retired Household*, *Age of Head of Household*, *Own Home*, *Black Household*, *Hispanic Household*, *Native American Household*, *Population Density*, *Household Size*, *Male Household*, *Educated Household*, *Ratio Working*, *Children*, *Student*, *Limited Youth*, *Eligible Household*),[35] a number of cell sites (*Cell Sites*) to control for inter-temporal changes in the quality of wireless service, and year dummies to account for time fixed effects and the potential impact of recession. Following the methodology of control function approach, I include estimated residuals from the equation (2).

Table 12 reports the estimation results for this model. The reference category is the outside option (no phone). The retained price residuals from the first step are not significant indicating that the hypothesis of price exogeneity cannot be rejected.

[35]See Macher et al., (2013).

The retained residual of *Lifeline Benefit* is negative and significant, confirming the hypothesis of the endogeneity of amount of subsidy.

Determinants of Telephone Subscription The estimates confirm findings in the existing literature; the major drivers of telephone demand are found to be price, income, age, home ownership, and quality of mobile service.[36] Lower prices increase the propensity of households to adopt a phone. The results, not surprisingly, indicate that the most price-sensitive groups of consumers are households below the poverty level, and with the ratio of income to the poverty level between one and two. For consumers in the two highest income categories, price coefficients are insignificant.

Wealthier and elderly households have a higher propensity to subscribe to the telephone network. Wealthier households tend to subscribe to both services, and are less likely to be wireless-only. The older the head of a household, the more likely the household is to subscribe to a landline only, and such households experience higher subscription levels as well. Home ownership is positively correlated with a choice of both phones and a landline, and families that own their home are less likely to be wireless-only. The results also indicate that improved quality of wireless service, measured by the number of cell sites, considerably increases the propensity of households to subscribe to wireless service only, and decreases the propensity of households to subscribe to only a landline.

Effects of Lifeline. Perfect Enforcement Turning to the principal variables of interest, the results reveal that higher level of Lifeline benefits increase the likelihood of subscription to telephone services among eligible households. The results also indicate that the FCC's wireless Lifeline initiative has had a positive and significant impact on the propensity to subscribe to landline only and to wireless only services. It is logical that implementation of subsidies for wireless prepaid service increases

[36] See, for example, Riordan (2002), Macher et al. (2012).

the propensity to subscribe to wireless service. It is quite surprising that the wireless Lifeline initiative increases the household propensity to subscribe to landline service. The possible explanation is that the extension of Lifeline made the subsidy program more popular among eligible households, perhaps due to advertising. More eligible households started enrolling in the program while subscribing to both wireline and wireless services.

The results indicate that the subsidy, in fact, has increased telephone penetration rates among eligible households, and the subsidization of prepaid wireless service has encouraged even more low-income households to subscribe to telephone network.

To test the goodness of fit of the mixed logit model, I estimate the predicted frequencies of alternatives. Table 13 shows that the estimated probabilities closely match the shares of customers choosing each alternative.

Counterfactual Policy Experiment. Perfect Enforcement Using the estimates from the mixed logit model, I conducted a policy experiment to see how elimination of Lifeline altogether, or its prepaid wireless part, would impact penetration rates and telephone choices of households in general. Table 14 provides the results of this exercise. The estimates show that if the prepaid mobile service were not subsidized, households would switch from being wireless only to both and landline only categories. Households would switch to the "both" category, because the two services are substitutes; hence, a household can partly substitute the more expensive service (wireless) for the less expensive one (landline). In addition, 147,034 households give up the telephone service altogether.

If the program were to be eliminated entirely, then over one million households would cancel telephone services (that is 23.6 percent of households that currently do not have telephone service); 60 percent of disconnected households are coming from the "wireless only" category, 30 percent from the "landline only" category, and 10 percent from the "both" category.

The estimated cost of adding a new subscriber in 2010 is $1,151 per year, while the actual average cost of the subsidy is $138 per household per year. That means that out of eight households that receive the subsidy only one household subscribes to telephone service because of the subsidy, and the other seven would have telephone service even if the subsidy were not available. Finally, the wireless Lifeline initiative has attracted new subscribers at an even higher expense of $2,835 per additional subscriber per year. That means that only one out of twenty households is a marginal subscriber; and the rest twenty are infra-marginal subscribers.

Inefficient Enforcement of Eligibility The FCC reported cases when non-eligible consumers enrolled in the low-income support programs due to self-certification of eligibility.[37] With this evidence, I consider a scenario with ineffective enforcement of subsidy rules, that is when non-eligible households are also able to receive the subsidy.

To estimate a mixed logit model in this setting, I include controls from the previous model, except the program benefits and control for the wireless Lifeline initiative enter the model without intersection with eligibility.

Table 15 reports estimation results for this model. The results closely mimic estimates under perfect enforcement scenario. The level of the Lifeline subsidy has a positive and statistically significant impact on the propensity of households to adopt a phone. Introduction of subsidies for prepaid wireless service enhances the subscription to all three telephone options, but coefficients are smaller than in the perfect enforcement scenario.

[37]See, FCC "Report and Order and Further Notice of Proposed Rulemaking" released on February 6, 2012.

Table 16 presents the goodness of fit test for this mixed logit model. The predicted frequencies of alternatives closely match the actual shares of consumers choosing each alternative.

Counterfactual Policy Experiment. Inefficient Enforcement Table 17 provides the results of the policy experiments. The elimination of the wireless Lifeline initiative results in a massive switch of wireless-only subscribers to landline and both services, where the majority would subscribe to a landline in addition to a cell phone. Furthermore, 76,001 households would cancel a phone service altogether. If the Lifeline program is eliminated entirely, then the majority of switching households would migrate to "wireless-only" category (2.2 million), while 401,911 households would give up the telephone service (8.8 percent of the total number of households that currently do not have telephone service).

The bottom line is, if non-eligible consumers are also able to receive a subsidy for telephone service, the penetration rates would slightly increase, but to a greater extent it would influence the telephone choices of households, not the subscription decision. Under this scenario, the overall cost of adding a new subscriber in 2010 is $3,093 per year, while the cost of adding a new subscriber under the wireless Lifeline initiative is $5,486 per year.

2.5 Discussion

An extensive body of literature has evaluated universal service and the policies implemented to achieve its ubiquity of access to the historical wireline network. Over the years, the Lifeline program has undergone significant changes that include changes in benefit levels, eligibility criteria, and services supported by this program. The existing literature does not provide sufficient research on universal service policies as they have evolved. This paper seeks to fill that gap and investigates if the low-income program has acted to promote connectivity of American households and at what cost.

The results reveal that when the rules of the program are strictly enforced and only eligible households are able to enroll in Lifeline, higher amounts of the subsidy increase the propensity of households to subscribe to telephone service. The policy experiment based on the estimates from the mixed logit model showed that if the wireless prepaid part of Lifeline were to be eliminated, 147,034 households would cancel telephone services. If the Lifeline program were to be terminated altogether, then over one million households would give up telephone services. The overall estimated cost of adding a new subscriber to the telephone network in 2010 is $1,151 per year; while the cost of adding a new subscriber under the prepaid wireless part of Lifeline is much higher - $2,835 per year.

Under the assumption that any household is able to enroll in the subsidy program, the results indicate that the higher Lifeline benefits encourage subscription to the telephone network. Introduction of subsidies to prepaid wireless service also has a positive impact on the likelihood of subscription to all three telephone options. However, in this setting, the subsidy to a greater extent influences the choice of telephone options, not the subscription decision. In this setting the estimated cost of adding a new subscriber to the telephone network in 2010 is $3,093 per year, while the cost of adding a new subscriber under wireless Lifeline initiative is $5,486 per year.

Future research may extend this model to explain low participation rates in the Lifeline program and dramatic differences in state-level enrollment. Another question that arises in this context is if the market power of telecommunications companies is compatible with the goal of universal service. In other words, further extension of this research might identify whether a regulatory approach, when the regulator compels telephone companies to offer affordable plans to low-income individuals, or the implementation of the subsidies is the more beneficial strategy to promote the goal of universal service.

In 2012 the FCC issued the new reform order for Lifeline and Link Up.[38] According to this order, Lifeline has been significantly changed, and Link Up was virtually eliminated. A Broadband Pilot Program (modification of Lifeline designed to promote broadband) has been implemented and is now ongoing in several states. This study can serve as a guidance for the analysis of the ongoing regulatory changes of the subsidy programs, as well as the investigation of the effectiveness of Lifeline for broadband.

[38]See, FCC "Report and Order and Further Notice of Proposed Rulemaking" released on February 6, 2012.

Chapter 3

International Telecommunications Demand

The long distance telecommunications industry has experienced several drastic changes in recent years. Over the past two decades, international carriers have encountered market liberalization, the telecom bubble and its aftermath, intense competition, rapid technological innovation, and subsequent price decline. In addition, the emergence of wireless telephony and Voice over Internet Protocol (VoIP) technology has drastically changed the profile of the telecommunications industry. While there exists a considerable literature on the demand for international calling, many rapid changes in the industry compel a fresh examination. Accordingly, the primary objective of this paper is to examine how the demand for international calling has evolved over time in light of these changes. It incorporates the factors that influence the volumes of incoming and outgoing telephone traffic between the country pairs. It extends the existing research by accounting for the emergence of VoIP telephony and including separate measures of the prices for fixed, mobile and VoIP services. It employs a two-equation dynamic simultaneous equation model that allows me to update existing estimates of price elasticities and analyze the issue of substitutability or complementarity of incoming and outgoing calls.

The paper utilizes a unique data set collected by TeleGeography that contains volumes of TDM calls and VoIP calls interconnected with the public switched telephone network (PTSN)[1] for a variety of country-pairs. The model accounts for call externality,[2] and employs a dynamic panel estimator to investigate the demand for international telephone calls for 24 countries over the 2010-2012 period. I find that the prices of telephone calls from fixed phones and VoIP have no significant impact on the demand for international calling, while price of calls from mobile phones has a negative and significant impact on the demand for international telephone communications. I estimate own- and cross-price elasticities of the volume of outgoing and incoming calls with respect to the price of calls from mobile phones. The estimated own-price elasticity of demand for international calls between mobile phones equals -0.40 for originating calls and -0.28 for incoming calls. The estimated cross-price elasticity of demand for international mobile calls equals -0.29 for originating calls and -0.26 for incoming calls. Negative cross-price elasticity indicates that incoming and outgoing calls are complements, rather than substitutes.

My results also support the expected pattern that higher volumes of trade and higher migration between countries increases demand for international calls. The results reveal that larger countries have higher demand for international communications than countries with smaller population. I find that countries that are spatially close to each other have higher demand for communications. Higher levels of fixed broadband adoption increase demand for international communications. Telephone

[1]The data does not contain information on VoIP calls made from one computer to another computer.

[2]Call externality, or reciprocal effect, means that the utility function of the consumer depends not only on the calls that she makes, but also on the calls that she receives since in both cases she receives information. Call arbitrage implies the possibility that the consumer in the higher tariff country will attempt to make the consumer from the lower tariff country pay for the larger part of calls. Since they both receive information during the call, the consumer that faces lower calling prices would call more frequently than the consumer that faces higher calling price.

proliferation does not appear to be significant in defining the volume of international telephone traffic.

Regulators and industry researchers have sought to keep pace with the changing nature of the international telecommunications industry, however there is inevitably some lag between the industry and regulation and research. The Federal Communications Commission (FCC) 2012 International Telecommunications Data Report, considered one of the best sources of data regarding international telephone traffic, says: "Interconnected VoIP services currently are not included in carriers' FCC Part 43 data submissions and are not reflected in this report. Their inclusion in future reports will result in an increase in reported traffic." According to the FCC report, outgoing traffic from the United States was 77.9 billion minutes in 2012, while TeleGeography[3] reports 135.2 billion of outgoing minutes from the US. Because VoIP traffic data is not collected by the FCC, the 57.3 billion minutes are not reflected in the Commission's report. International calling generated by VoIP services now constitutes a substantial and growing component of international calling markets and VoIP providers are important participants in international telephony markets. As such, it is impossible to fully understand the market of international calling services without accounting for international VoIP traffic. Failure to do so distorts such important matters as demand forecasting, understanding the current price trends, analyzing market competitiveness, establishing and achieving efficient settlement rates (i.e. the price paid by the originating company to the receiving company to connect international calls), and preventing anticompetitive behavior by the telecommunication carriers.

International calling has been especially impacted in recent years in two major developments. First, wireless telephony experienced unprecedented growth in the recent years. According to the International Telecommunications Union (ITU), the

[3]TeleGeography Report, 2013.

number of wireless subscribers outgrew the number of fixed-line subscribers in 2001[4] and reached 6.6 billion in 2013. Another phenomenon that has accelerated the demand for wireless telephony is mobile-to-fixed substitution.[5] Telephone subscribers and consequently voice traffic has migrated from traditional landlines to wireless networks. Figure 12 shows the growth of fixed and mobile international telephone traffic over the 2008-2012 period. The ratio of traffic through fixed networks vs mobile networks shifted from 66:34 in 2008 to almost 50:50 in 2012. The improved quality of wireless networks and considerable decrease in wireless prices has drastically changed the way people around the world communicate with each other. Taylor (1994) wrote that the completion rate of international telephone calls (in the mid-1970s) was about 50 percent. The reasons for that included limited equipment at some international locations and constrained availability of people. The person had to be at a particular location at a particular point of time. Development of mobile telephony eliminates this problem - subscribers of wireless service are available anytime and anywhere.

Second, development of broadband (high-speed Internet) coupled with historically high rates for international calls via traditional circuit-switched networks encouraged development of alternative technology for voice communications - VoIP telephony. In its infancy, the VoIP market was quite small[6] and its quality was rather poor. Recent increases in broadband adoption and internet performance (higher speeds) has allowed more subscribers the opportunity to communicate using VoIP at a lower cost and more reliably. VoIP communications are available through the numerous devices: specialized VoIP telephones, regular telephones with a VoIP adapter, smartphones, tablets or computers. Additionally, VoIP allows extra features that are not available through

[4]See, http://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

[5]Sung et al. (2000), Sung, Lee (2002), Rodini et al. (2003), Hodge(2005), Vogelsang (2012), Ward and Zheng (2012), Macher et al. (2012)

[6]See, Rappoport et al. (2004).

regular telephones, such as instant messaging, web conferencing and video calls. Figure 13 shows the evolution of the traditional circuit-switched telephony (TDM) and VoIP originated international traffic over the period 2008-2012. The ratio of traffic through TDM vs VOIP shifted from approximately 75:25 in 2008 to 64:36 in 2012.[7] The growth rate of VoIP traffic has considerably outpaced that of TDM traffic. The growth rate of VoIP calls was around 21 percent in 2012, while the volume of TDM traffic grew by only 2.4 percent.

VoIP represents another phenomenon in the telecommunications industry - the convergence of the internet and telephone technologies. VoIP allows users to make voice calls using a broadband internet connection instead of a regular phone line. Unlike TDM that establishes a dedicated circuit between the parties to a voice transmission and cannot be used for another call until the originating call is concluded, VoIP relies on packet-switching, which divides the voice transmission into packets and sends them over the fastest available route. Packets may travel through completely different routes, however the conversation is reassembled in the correct order before being passed on the VoIP application. IP gateways serve as access points from the IP network to the PSTN (Public Switched Telephone Network). IP gateways also perform such functions as call termination, determination of call direction, user verification and billing. VoIP uses available bandwidth more efficiently than circuit-switched telephony and allows providers to maintain a single IP network for both voice and data.[8] As a result of the bandwidth efficiency and low costs that VoIP technology can provide, businesses are migrating from traditional copper-wire telephone systems to VoIP systems to reduce their monthly telephone costs. Also, VoIP offers some extra features

[7]Total traffic does not include voice calls conducted from computer to computer. For example, traffic from Skype to Skype is not included.

[8]See, Petition for Declaratory Ruling that AT&T's Phone-to-Phone IP Telephony Services are Exempt from Access Charges, WC Docket No. 02-361 (April 21, 2004).

attractive to the customers, such as conference calls, portability, and other business applications. A potential impediment for consumers to utilize VoIP technology is limited availability of high-speed internet. Since VoIP uses the internet as backbone, consumers need broadband access with a decent speeding order to conduct/receive high-quality calls via VoIP services. Some consumers may face high switching costs from traditional circuit-switched telephony to VoIP; for instance, it might be hard for older people to learn how to use a computer to make a call.

To date, the majority of existing literature has estimated demand for international calls conducted via the traditional circuit-switched telephony (TDM). The study by Rappoport et al. (2004) is the first attempt to estimate demand and elasticities for VoIP services by examining consumers' willingness-to-pay in a survey conducted in March and April of 2004. A significant difficulty with the inclusion of VoIP traffic when estimating the demand for international calls is a lack of reliable holistic data. This research aims to address this gap in the literature.

The rest of the paper is organized as follows. Section 2 provides a brief review of the literature. Section 3 develops an econometric model of international calling demand. Section 4 discusses the data used for empirical estimation and Section 5 provides the statistical results. Section 6 summarizes and concludes the paper.

3.1 Existing Literature

The telecommunications industry, specifically the means of communications, has greatly changed over the years. The research topics have evolved in tandem with these changes.

Earlier studies of demand for international communications (e.g. Lago (1970), Yatkaris (1972), and Rea and Lage (1978)) focus on telephone, telegraph and telex services. Lago (1970) investigates the demand for telephone, telegraph and telex services. The paper aims to identify the main factors that underlie international telecommunications demand and investigate the substitutability/complementarity of the three services. The empirical analysis draws upon data for telephone traffic between the US and 26 foreign countries for the 1962-1964 period. The paper finds that no price substitution exists for telephone, telegraph and telex. The estimated price elasticity of demand for international telephone calling is -1.249. The results show that international trade and tourism expenditures are important factors that influence demand for international communications.

Yatrakis (1972) extends Lago's model by including demographic variables, such as language commonality between two countries, and the number of tourists and immigrants. The empirical analysis is based on data for outgoing traffic from the US to 46 foreign countries for 1967. The paper estimates that the price elasticity of demand for international telephone calls equals -0.82.

Rea and Lage (1978) present estimates of demand elasticities for international telephone, telegraph and telex services for the 37 major international routes for the 1964-1973 period. The results of this empirical analysis show that the demand for telephone services is highly price elastic, with a range of 1.7-1.9. The paper also finds that the telephone and telegraph services are complements and that the demand for telephone services is highly and positively correlated with the real household income.

Bewley and Fiebig (1988) extend Lago's model by distinguishing between the demand for access and usage. In other words in their model the consumer decides whether to make an international call and chooses the length of the call. The paper draws upon the data for calls originating in Australia for the 1976-1983 period. The model analyzes demand for three types of services: International Subscriber Dialing (ISD), person-to-person and station-to-station. The results show that the three services are substitutes and the number of calls is price inelastic in the short-run, but price elastic in the long-run. The results indicate that the length of call is highly price elastic and price elasticities are remarkably greater in the long-run.

Acton and Vogelsang (1992) propose point-to-point demand model and assume that the calls in one direction can affect return calls though reversion and reciprocity. The paper examines the volume of originating and terminating calls between the United States and 18 West European counties from 1979 to 1986. Inbound and outbound calls are modeled as functions of prices from the country of origin and prices of return calls from the country where the call terminated, volume of trade between the countries, the percentage of employment in major sectors of the economy, the number of telephones, and the price of telex services (a potential alternative form of communication). Their results indicate negative own and cross-price elasticities for originating and terminating calls (-0.36 and -0.49 correspondingly), which imply that inbound and outbound calls are economic complements. The results indicate a positive coefficient on the number of telephones in each country. Volume of trade is found to have a statistically insignificant effect on telephone calls. The paper finds that growth in the economic sectors of agriculture, restaurants and hotels, banking and financial, and manufacturing causes an increase in international calling, whereas, international calling decreases when a greater fraction of people are employed in the transportation sector. Even though the theoretical model includes simultaneous equations with the reciprocal effect, the empirical analysis conducted using reduced form equations without including the reciprocal effect or accounting for endogeneity.

The majority of subsequent papers use models that are similar to the one used by Acton and Vogelsang (1992). Their results have been improved by accounting for other factors that might influence demand for international telephone calls and incorporating estimators that account for arbitrage, reciprocal effects, and potential endogeneity.

Hackl and Westlund (1995, 1996) use data for voice calling from Sweden to Germany, the US, UK, Denmark, Finland, and Norway over the 1976-1990 period. They develop a model with time-varying price elasticity and estimate the model for each country. Their results show that all European countries except the US exhibit price elastic demand, and that the price elasticity decreases over the observed period of time. The results for the US are different; their estimates show price elastic demand in the earlier period of time, but (absolute) price elasticity decreasing in the mid-eighties to a value close to zero.

Sandbach (1996) analyzes telephone traffic in both directions between major Western European countries and a range of countries worldwide. He focuses on the impact of callback and arbitrage opportunities because of differences in international calling rates between countries. He finds evidence of the callback effect on the routes where the arbitrage opportunities exceed a certain threshold (about US $0.90 per minute).

A study by Garin-Munoz and Perez-Amaral (1998) examines telephone traffic from Spain to a group of African and Asian countries for the 1982-1991 period. The estimated price elasticity equals -1.31. The study also finds the existence of the reciprocal calling effect and a positive impact of number of foreign tourists on the number of calling minutes between countries. In their later paper, Garin-Munoz and Perez-Amaral (1999) estimate demand for telephone traffic from Spain to 24 European countries for the 1981-1991 period. Their results indicate that price elasticity of demand equals -0.81; as in the previous paper, they find that the volume of trade and the number of foreign residents have a positive impact.

Karikari and Gyimah-Brempong (1999) estimate international calling demand between the US and 45 African countries for the 1992-1996 period. They account for call externality and arbitrage by using a simultaneous equations model. They estimate that demand for calls from the US to African countries is price inelastic, and estimate that short run and long run own-price elasticities are -0.0423 and -0.1238, respectively. The demand for calls to the US originating in African countries is more price elastic with short-run and long-run elasticities of -0.4426 and -1.4241, respectively. They assess that cross-price elasticities of demand are negative for traffic originating in the US, and cross-price elasticities are positive for telephone calls originating in African countries. These results indicate that for the US residents, calls between the US and African countries are complements; while for the residents of African countries telephone calls between the US and African countries are substitutes. Other findings of this research are that the telephone traffic increases with income and trade.

Telephone traffic imbalances are modeled in the paper of Alleman, Madden and Savage (2000). The findings suggest that asymmetric market structure and price differentials are significant factors that explain the difference in volumes of incoming and outgoing telephone traffic. For low and high income countries GDP per capita is another important cause of traffic imbalances. The model is estimated using data for 82 countries for 1991-1995.

Madden, Savage and Tipping (2001) estimate demand and price elasticities for international calls for 10 members of European Union prior to full market liberalization on January 1 1998. The empirical analysis is provided using bilateral market data from 1990 to 1995. Model estimates suggest that price elasticities of outgoing traffic vary in the range of -0.175 and -0.456, and price elasticities for incoming traffic vary in the range of -0.215 and -0.674.

Ford and Jackson (2004) estimate demand and price elasticities of demand using outgoing telephone traffic data from the US to 28 foreign countries for the 1985-1994 period. The estimates show that the short-run price elasticity of demand equals -0.28, while the long-run elasticity equals -1.04. Their results show that the outgoing and incoming traffic are complements. They also found that the volume of trade between the two countries has no statistically significant impact on the volume of traffic originating from the US.

Rappoport et al. (2004) perform the first attempt to estimate the demand for VoIP services based on the survey conducted in 2004 in which respondents were asked about their willingness-to-pay for VoIP services. The elasticities of demand are obtained using the kernel method and they vary in the range of -0.50 for a fixed price of $10 per month, to -3 for a fixed price of $70 per month.

Agiakloglou and Yannelis (2006) employ different econometric techniques to assess price elasticities of demand for international calls. This paper uses data for calls from Greece to five foreign countries: Australia, the US, Canada, U.K and Germany for the 1997-2003 period. The data sample restricted to the traffic reported by the incumbent company and mobile providers. The paper tests two models with constant and time-varying price elasticities. The results indicate that peak prices have more explanatory power than off-peak prices, and the model with time-varying price elasticity fits data slightly better than the model with constant price elasticity. The estimated price elasticities of demand range from -0.3 to -1.12 for Australia for the model with the time-varying price elasticity. Under the assumption of constant price elasticities, the results are quite different and price elasticities vary from -0.09 to -0.42.

Perkins and Neumayer (2013) focus on the role of migrants in determining the patterns of international telephone traffic flows. The empirical analysis is based on the TeleGeography data for 160 countries over 2001-2006. The paper accounts for a variety of factors such as the number of migrants, short-term visitors, trade and FDI, distance between countries, language similarity, per capita income and population. However, the analysis does not account for the level of prices. The results indicate that migrant stock is a significantly important factor that determines the volume of telephone calls. The other results confirm the finding in the previous studies, such as that spatial proximity increase the total volume of telephone calls, as well as the higher volume of total trade. As previously found, higher income per capita and common language result in higher volume of telephone calls.

Table 18 summarizes the results obtained in the studies discussed above.

Another strand of literature analyzes the prices of international calls. Madden and Savage (2000) develop a model that would explain the price differentials of international calls between countries. Their paper finds that the settlement rates are significant determinants of the prices changed to consumers. The results reveal that that market concentration, traffic volume, labor productivity, digitalization, and the level of competition at either end of bilateral market are important determinants of prices. The model estimation is based on data for telephone traffic between the US and 39 foreign countries for the 1991-1994 period.

Carter and Wright (1994) in their theoretical work build a model in which vertical monopolies trade essential inputs with each other. Telecommunications industry is one of the obvious applications of their model with the key result that the settlement rates are important determinants of retail prices of telephone service.

Wright (1999) uses this result and models settlement rates between international telecommunications carriers to better understand retail prices. The empirical analysis is based on the data for international calls between the US and foreign countries from 1980-1996. The paper establishes that higher income nations effectively subsidize the telecommunications sector in lower income nations through imbalances in the flow of international calls. The paper finds that settlement rates are increasing with the income disparity between the US and the foreign country. Settlement rates increase with the distance between countries, decrease as population of the foreign country increases and increase as the land area of foreign country increases.[9] Another important finding is that greater competition in the US and foreign countries generally decreases settlement rates.

Finally, there is evidence that some governments are challenged by the development of VoIP telephony and there are concerns that it would slow down development of telecommunications infrastructure. Martha Garcia-Murillo (2004) assesses the impact of development of VoIP telephony on the deployment of telecommunications infrastructure and she finds that there is no evidence of negative impact of VoIP on infrastructure.

The present study updates estimates of demand for international calls obtained in the existing literature using a more recent dataset for the 2010-2012 period. I account for the calls conducted via the new VoIP technology. Due to data limitations, none of the existing studies have estimated demand for the international calls transmitted via TDM and VoIP. My model includes various measures of prices: prices of calls via wireline networks, mobile networks and VoIP. I account for the possibility of arbitrage and reciprocal calling effects. The next section presents the model and econometric specifications.

3.2 Model

I follow the model of Acton and Vogelsang (1992) that accounts for call externality or call reciprocity effects. A call externality arises from the fact that there are

[9] Land area here serves as an approximation of costs of providing the national link (carrying the call within the country and delivering it to the customer).

Table 18: Estimated Price Elasticities from Previous Studies

Study	Dependent Variable	Own Price Elasticity	Cross Price Elasticity	Data
Lago, 1970	Total number of minutes between the US and foreign country	-1.249		Telephone traffic between the US and 26 foreign countries, 1962-1964
Yatkars, 1972	Total number of outgoing minutes from the US to foreign country	-0.82		Outgoing traffic from the US to 46 foreign countries, 1967
Rea, Lage 1978	Outgoing minutes from the US to foreign country	-1.7,-1.9		Outgoing traffic from the US to 37 foreign countries, 1964-1973
Acton, Vogelsang (1992)	Outgoing minutes from the US to foreign country	-0.36 (-3.85)	-0.05 (-1.12)	Calls between the US and 17 West European countries, 1979-1986
	Number of minutes terminating in the US	-0.49 (-5.70)	0.17 (0.74)	
Garin-Munoz, Perez Amaral (1988)	Number of minutes originating in Spain per line	-1.31		Calls from Spain to Asian and African countries, 1982-1991
Hackl, Westlund (1995)	Number of minutes originating in Sweden	SR: -0.12 to -0.51 LR: -0.37 to -.1.8		Calls from Sweden to the US, UK, Germany, Denmark, Finland and Norway, 1976:1-1990:12
Karikari, Gyimah-Brempong (1999)	Telephone calls from the US per truck line	SR: -0.04 LR: -0.12	-0.2 -0.58	Calls between the US and African countries, 1992-1996
	Telephone calls from African countries per truck line	SR: -0.44 LR: -1.42	0.15 0.49	
Madden, Savage, Tipping, 2001	Incoming and outgoing traffic for 10 EU countries	-0.175, -0.456		Calls between 10 EU countries, 1990-1995
Ford, Jackson (2004)	Number of munites originating in the US	SR: -0.28 LR: -1.04		Calls between the US and 28 countries, 1985-1994
Agiakloglou and Yannelis, 2006	Outgoing minutes from Greece	-0.3, -1.12		Outgoing traffic from Greece to 5 foreign countries, 1997-2003
Rappoport et al. (2004)	Survey of willingness-to-pay for VoIP	-0.5, -3		Survey of 8,000 US households, 2004

two participants in the telephone call and only one participant pays while both are "consuming" the good. The calling externality is created by calling a party that does not have to pay for being called.

Acton and Vogelsang argue that the calling externality is likely to be substantial, because high international tariffs reduce nuisance calls and increase incentives for free riding for those who want to receive a call rather than initiate one to escape payments. Systematic differences in international tariffs distribute the externalities asymmetrically.

I assume that during the telephone call, calling parties produce "information" in a consumer production function with the incoming and outgoing calls as inputs. Both parties derive utility from the information contained in telephone call, but not from the telephone call "*per se*." Furthermore, the interaction of both callers is necessary to derive utility from the telephone calls, creating an access or network externality.

The call externality implies that calls from one country affect calls to the other country. The effect may go in two directions; on the one hand, incoming calls may serve as substitutes for outgoing calls from one country to another. On the other hand, the more consumers from one country that are calling to consumers in another country, the more calls are initiated in the opposite direction. In this case, outgoing and incoming calls are complements. This effect is called a *reciprocal call effect* in the existing literature. It is unclear which effect is prevalent.

I assume that consumer in the domestic (or, originating) country (d) maximizes

$$u^d = u^d(x^d, q^d, q^f), \tag{3.1}$$

$$\text{s.t. } x^d + p^d q^d \leq y^d,$$

where x^d is the consumption of composite good, q^d is the quantity of outgoing calls, and q^f is the quantity of incoming calls, y^d is d's income, p^d is a price of international telephone call from d's country of residence to f's country of residence, and the price of composite good normalized to one.

Consumer (f) in the foreign (or, terminating) country solves the analogous problem. Simultaneous solution to d's and f's maximization problems gives $q^{d\star}$ and $q^{f\star}$

$$q^{d\star} = f(y^d, p^d, q^{f\star}) \qquad \text{and} \qquad q^{f\star} = g(y^f, p^f, q^{d\star}). \tag{3.2}$$

The general form of the demand for international calling for domestic consumer is given as:

$$q^d = \phi(p^d, p^f, q^f, y^d). \tag{3.3}$$

his is especially true for the rapidly changing technology coupled with the regulatory changes typical for the telecommunications industry. In a rapidly changing environment, it is necessary to allow for an adjustment in consumer behavior to a variable desired demand. The adjustment process is taken from the Bewley and Fiebig (1988) model:

$$\frac{\partial q_t^d}{\partial t} = \alpha(q_t^{d\star} - q_{t-1}^d). \tag{3.4}$$

The derivative of q_t^d is approximated by its first difference:

$$q_t^d - q_{t-1}^d = \alpha(q_t^{d\star} - q_{t-1}^d). \tag{3.5}$$

Then, substituting the demand equation into this adjustment process and solving for q_t^d, the consumer demand for the international calling is given by the following equation:

$$q_t^d = \phi'(q_{t-1}^d, p_t^d, p_t^f, q_t^f, y_t^d). \tag{3.6}$$

I assume that the level of international calling demand adjusts instantaneously to the desired level of demand when any of the explanatory variables change. In other words, demand in the current period does not depend on demand in the previous periods. Then, aggregating over all households in the domestic country that make calls to a foreign country, the general international calling demand function is given as:

$$Q_t^d = \Phi(p_t^d, p_t^f, Q_t^f, Y_t^d), \tag{3.7}$$

where Q_t^d is the aggregate demand for international calls to the foreign country of the consumers in the domestic country in period t, and Q_t^f is the demand for international calls in the foreign country to the domestic country in period t, and all other variables are defined above. The aggregate demand in the foreign country can be derived in a similar fashion:

$$Q_t^f = \Psi(p_t^f, p_t^d, Q_t^d, Y_t^f). \tag{3.8}$$

Equations (3.7) and (3.8) indicate that Q_t^d and Q_t^f are jointly determined from a system of simultaneous equations.

$$\begin{cases} Q_t^d = \Phi(p_t^d,\ p_t^f,\ Q_t^f,\ Y_t^d), \\ Q_t^f = \Psi(p_t^f,\ p_t^d,\ Q_t^d,\ Y_t^f). \end{cases} \tag{3.9}$$

difference in calling rates creates the opportunity for arbitrage. Countries with the better calling "deals" compared to their counterparts will have higher outgoing call traffic than incoming traffic. Arbitrage opportunities were investigated in the previous studies[10]. Based on the results from the previous studies, I assume that the arbitrage effect increases with the differences in international calling prices between two countries. Therefore, I assume that the arbitrage effect is a function of the price ratio between the pair of countries and include the arbitrage effect in the system of simultaneous equations:

$$\begin{cases} Q_t^d = \Phi(Q_{t-1}^d,\ p_t^d,\ p_t^f,\ Q_t^f,\ Y_t^d, p^d/p^f), \\ Q_t^f = \Psi(Q_{t-1}^f,\ p_t^f,\ p_t^d,\ Q_t^d,\ Y_t^f, p^f/p^d). \end{cases} \tag{3.10}$$

3.2.1 Econometric specification

To estimate the system of simultaneous equations (3.9) I need to specify the functional forms and define variables that are included in the demand equations. I follow the previous studies (Acton and Vogelsang (1992), Sandbach (1996), Garin-Munoz and Perez-Amaral (1998)) and specify the demand equations in double logarithmic forms. This functional form allows for interpreting the regression coefficients as elasticities.

The TeleGeorgraphy data include calls using the “old” TDM and “new” VoIP technologies. Unfortunately, the way the data are collected does not allow for separately estimating the demand for each type of calls. For this reason, the dependent variable is an aggregate amount of TDM and VoIP calls. I include measures of prices for the calls from fixed-to-fixed, fixed-to-mobile, mobile-to-fixed and mobile-to-mobile phones. The model also includes measures of VoIP prices; I include prices of calls from Skype to different world regions. Measures of prices allow me to analyze which

[10] E.g. Acton and Vogelsang (1992), Sandbach (1996).

prices are significant determinants of telephone calls and estimate price elasticities of incoming and outgoing calls.

To account for consumers' wealth, I include GDP per capita (Y). I include volume of total international trade to proxy the amount of business activity between countries (*Total Trade*). To account for market size, I include proxies of access, such as penetration of wireline and wireless phones and penetration of internet and broadband ($Access_m$), where m represents the number of variables that measure access to the telephone network.

Existing studies have found[11] that the demand for international telephone calls is related to the market size. The size of market (or the calling population of interest) is generally proxied by the population. I use population of foreign and domestic countries to account for the size of the community of interest of the calling party (*Population*).

Migration is frequently found to be a significant underlying factor of demand for international calls. I include total amount of migrants born in the country where the call is originated and the country where the call in terminated in the country-pair (*Bilateral Migration*).

I include variables that are generally recognized to influence ties between two countries, such as a common border, a common official language, common currency, and distance. I denote this group of variables $CountryTies_k$, where k equals the number of variables included in this group.

To account for the systematic differences in demand across countries due to unobserved components, I include country dummies. Given the rapid pace of technological change in the telecommunications, it is likely that the demand has a temporal effect that is constant across countries. To account for the technological change, I include time varying fixed effects in the demand equations.

[11] See for example, Garin-Munoz and Perez-Amaral (1998).

Accounting for all the factors mentioned above, the demand function for international telephone calls between countries can therefore be specified as:

$$\ln Q_t^d = \alpha_0 + \alpha_1 \ln Q_t^f + \alpha_2 \ln p_t^d + \alpha_3 \ln p_t^f + \alpha_4 \ln Y_t^d + \alpha_5 \ln Y_t^f + \\ + \alpha_6 Total\ Trade_t + \alpha_7 Bilateral\ Migration_t + \alpha_8 Population_t^d + \alpha_9 Population_t^f + \\ + \alpha_{10m} Access_{mt}^d + \alpha_{11k} CountryTies_{kt} + \delta_i + \lambda_t + \epsilon_{it}, \quad (3.11)$$

where δ_i and λ_t are unobserved country and time fixed effects, ϵ_{it} is a stochastic error term, and all other variables are defined above. Similarly, the demand for international telephone calls in the foreign country can be written as:

$$\ln Q_t^f = \beta_0 + \beta_1 \ln Q_t^d + \beta_2 \ln p_t^f + \beta_3 \ln p_t^d + \beta_4 \ln Y_t^f + \beta_5 \ln Y_t^d + \\ + \beta_6 Total\ Trade_t + \beta_7 Bilateral\ Migration_t + \beta_8 Population_t^f + \beta_9 Population_t^d + \\ + \beta_{10m} Access_{mt}^f + \beta_{11k} CountryTies_{kt} + \rho_i + \theta_t + \xi_{it}, \quad (3.12)$$

where ρ_i and θ_t are unobserved country and time fixed effects respectively, and ξ_{it} is a stochastic error term.

From equations (3.11) and (3.12) the own-price and cross price elasticities of demand for calls in the country D are expressed in the following way:

$$\partial \ln Q^d / \partial \ln p^d = [\alpha_1 \beta_3 + \alpha_2]/(1 - \alpha_1 \beta_1) \quad (3.13)$$

$$\partial \ln Q^d / \partial \ln p^f = [\alpha_1 \beta_2 + \alpha_3]/(1 - \alpha_1 \beta_1) \quad (3.14)$$

The own- and cross-price elasticities for the foreign country are calculated in the similar way.

rom equations (3.11) and (3.12) the own-price and cross price elasticities of demand for calls in the country D are expressed in the following way:

$$\partial \ln Q^D / \partial \ln p^D = [\alpha_2 + \alpha_6 - \alpha_5 \beta_6]/(1 - \alpha_5 \beta_5) \tag{3.15}$$

$$\partial \ln Q^D / \partial \ln p^F = [(\beta_2 + \beta_6)\alpha_5 - \alpha_6]/(1 - \alpha_5 \beta_5) \tag{3.16}$$

To examine if price differences between countries result in arbitrage, I include a ratio of call prices between the two countries (p^d/p^f). Then the equation of demand for the outgoing international calls in the domestic country is given as:

$$\ln Q_t^d = \tilde{\alpha}_0 + \tilde{\alpha}_1 \ln Q_{t-1}^d + \tilde{\alpha}_2 \ln Q_t^f + \tilde{\alpha}_3 \ln p_t^d + \tilde{\alpha}_4 (\ln p_t^d - \ln p_t^f) + \tilde{\alpha}_5 \ln Y_t^d + \tilde{\alpha}_6 \ln Y_t^f + \\ + \tilde{\alpha}_7 Population_t^d + \tilde{\alpha}_8 Population_t^f + \tilde{\alpha}_9 Access_t^d + \tilde{\alpha}_{10} CountryTies_{kt} + \tilde{\delta}_i + \tilde{\lambda}_t + \tilde{\epsilon}_{it}. \tag{3.17}$$

And the demand for international telephone communications in the foreign country is given as:

$$\ln Q_t^f = \tilde{\beta}_0 + \tilde{\beta}_1 \ln Q_{t-1}^f + \tilde{\beta}_2 \ln Q_t^d + \tilde{\beta}_3 \ln p_t^f + \tilde{\beta}_4 (\ln p_t^f - \ln p_t^d) + \tilde{\beta}_5 \ln Y_t^f + \tilde{\beta}_6 \ln Y_t^d + \\ + \tilde{\beta}_7 Population_t^f + \tilde{\beta}_8 Population_t^d + \tilde{\beta}_9 Access_t^f + \tilde{\beta}_{10} CountryTies_{kt} + \tilde{\rho}_i + \tilde{\theta}_t + \tilde{\xi}_{it}. \tag{3.18}$$

If consumers take advantage of the price differences, then the coefficients $\tilde{\alpha}_4$ and $\tilde{\beta}_4$ will be positive and significant.

3.3 Data

I examine telephone traffic between countries from four world regions: Asia, Europe, Latin America and Caribbean, and US and Canada[12] over the 2010-2012 period. Data are taken from the TeleGeography Report and Database. Traffic data are based on TeleGeography's annual survey of international carriers. Survey information is supplemented by data obtained from carriers' financial and regulatory filings. For the majority of countries, TeleGeography collects data on 90-95 percent of a country's traffic, and estimates traffic volumes for the smaller carriers. The data contain minutes of telephone calls between a variety of country-pairs, and not only aggregated volume of calls of all partner countries, which distinguishes this dataset from the datasets used in the previous studies. This allows an estimation of own- and cross-price elasticities of demand, as well as an estimation of reciprocal effect if any exists.

The database includes the volume of calls from fixed and mobile phones transported over the international segment of a carrier's network as either TDM or VoIP, which allows a more complete analysis than previous studies that focused only on TDM. Despite the inclusion of VoIP data, the data set has two significant limitations. First, TeleGeography does not factor the points of origination and termination into whether traffic is counted as TDM or VoIP. For instance, when a call is placed on a traditional fixed-line phone to another TDM-base phone, but transported as VoIP

[12]The countries in the sample are: Austria, Belgium, Brazil, Canada, Czech Republic, Denmark, Finland, France, Germany, Hong Kong, India, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Russia, Spain, Sweden, Switzerland, United Kingdom, and the United States.

over the international segment, this call would be counted as “VoIP.” In this dataset, I cannot distinguish if end users chose to use VoIP telephony and paid the lower VoIP rates, or the call was simply transported over VoIP network with the customer being unaware of that.

Second, computer-to-computer traffic (e.g, Skype-to-Skype) is excluded from the traffic data.[13] TeleGeography estimates that Skype[14] provided 160 billion minutes of cross-border voice and video communications service in 2012, and the estimated international traffic increased by almost 34 percent to 214 billion minutes in 2013. Figure 14 shows that if the Skype traffic were added to the volume of international calls, international voice traffic would have grown at a rate of 12 percent in 2012 and 2013 (comparing to the reported 8 percent growth rate in 2012 and 7 percent growth rate in 2013); close to the historic average of 13 percent of annual growth.[15] However, the data captures the calls conducted from computer to the telephone and *vica versa* (e.g., from Skype to telephone). This allows me to estimate demand for the VoIP calls interconnected with PTSN networks.

Taking these two limitation of the data into account, I use total originating Q^d (or terminating Q^f) minutes of calling in the reporting country as the dependent variable. In future work, it would be desirable to disaggregate TDM and VoIP minutes to assess the degree of substitution between these two technologies. The sample I use for the estimation accounts for approximately 20 percent of the total world telephone traffic in each year. Figure 15 shows that the proportions of TDM to VoIP traffic for each year in my data sample are very close to the ones in the data collected by TeleGeorgraphy worldwide reported in Figure 13. Table 19 shows outgoing and incoming minutes of

[13]TeleGeorgraphy data include Skype-to-phone traffic.

[14]TeleGeography report notes that Skype is by far the dominant provider of consumer VoIP service

[15]See teleGeography report, 2013.

international calls by country as a percent of total international traffic. The country that originates the most traffic is the United States, while the country that terminates the most traffic is India.

The price measures used in my analysis are retail prices reported in the TeleGeography report. Rates are expressed as a price per minute, based on a 3-minute call. Rates are provided for calls from fixed to fixed phones, from fixed to mobile phones, from mobile to mobile phones, and from mobile to fixed phones.[16] TeleGeography reports calling rates for peak and off-peak periods. The existing literature conventionally uses either average rate, or peak time rate. In this analysis I use prices at peak times as well.

The statistics based on the outgoing aggregate traffic show that the majority of the international calls are conducted via wireless networks. According to the TeleGeography report, the number of mobile subscriptions worldwide exceeds 6.4 billion, which is 5.3 times the number of fixed subscribers. Figure 12 shows that a substantial part of the international telephone traffic is transmitted via wireless networks and the volume of mobile to fixed traffic worldwide reached approximately 50:50 in 2012. TeleGeography does not report telephone traffic disaggregated into mobile and fixed for country-pairs. This disaggregation is available for each country and each of its counterparts. Thus, the share of mobile traffic in my data sample is unknown, but assumed to be substantial and close to that reported by TeleGeography worldwide.

Since calls from landline and mobile phones represent significant parts of the international telephone traffic, I include measures of prices of both services. Table

[16]To test the credibility of the pricing data I compared prices reported in the TeleGeography report with prices reported by Eurostat for year 2010. Eurostat reports standard rates in euros for 10 minute call from European countries to the US. I converted Eurostat rates to dollar equivalents and calculated a correlation between derived Eurostat rates and TeleGeography standard rates. The estimated correlation of 0.85 indicates that the prices reported in the TeleGeography report are very close to the prices reported by Eurostat.

20 shows that prices of calls from fixed phones to fixed phones are highly correlated with prices of calls from fixed phones to mobile phones. Prices of calls from mobile phones to fixed calls are highly correlated with prices of calls from mobile phones to mobile phones. In order to avoid multicollinearity in the model, as a measure of prices I include prices of calls from mobile to mobile phones and from fixed to fixed phones.

VoIP traffic represents a significant part of international calls, hence I include measure of VoIP calls. My data sample includes calls from Skype to telephone and *vica versa*. According to TeleGeography, Skype provided about 50 percent of international VoIP minutes in 2012. TeleGeography reports average Skype calling rates for five regions[17] for calls from Skype to fixed and mobile phones.

Income is measured as the nominal GDP per capita (Y) in US dollars for each country in each year. Current GDP and population ($Population$) for each country were obtained from the World Bank. *Total Trade* is measured as the volume of total trade (sum of exports and imports) between two countries. Trade data are taken from the International Monetary Fund's "Direction of Trade Statistics" report.

Migration is found to be one of the significant factors that influence the volume of international telephone calls. I use the Global Migrant Origin Database,[18] which contains bilateral migrant stocks for 226 countries. Most of the data were collected as a part of the 2000 round of censuses. While the database does not contain the most recent information, I assume that it is still representative of contemporary migration flows. Migration is measured as the stock of migrants in a country j from a country of origin i. In the model, I include the sum of migrant stocks in the country-pair, i.e. the sum of the number of migrants from country i in country j and the number of migrants from country j in country i ($Bilateral\ Migration$).

[17] Africa, Asia, Europe, Latin America and Caribbean, and U.S. and Canada

[18] http://www.nsd.uib.no/macrodataguide/set.html?id=24&sub=1

To account for the number of potential users of each technology, TDM and VoIP, I obtain data from the International Telecommunication Union (ITU) on the number of fixed phones per 100 inhabitants *(Fixed Phones per 100 Ppl)* in each country, the number of mobile phones per 100 inhabitants in each country *(Mobile Phones per 100 Ppl)*, and the percent of the population that use the Internet (*Internet*) in each country. These are used as measures of access to the various telephone services.

Because some data are missing, the estimation is based on 690 country-pairs over the 2010-2012 period. Table 21 presents summary statistics for the data sample used in the estimation. On average, there are more incoming than outgoing calls, 492.6 million and 428.5 million respectively. More than 60 percent of outgoing and incoming traffic is transmitted via TDM. Most of the countries have a relatively high GDP per capita; average income per capita is $45,168. The summary statistics show that international calls from fixed phones are cheaper than calls from mobile phones. The average price of a phone call from a landline is between $0.77 and $0.88, while the average price of a phone call from a mobile phone is about 1 dollar. Skype rates are much cheaper than the rates offered by the telecommunications carriers: it costs on average $0.05 cents to call from Skype to a landline, and $0.20 cents to a cell phone. Table 21 shows that there is high variation in the levels of trade among countries in the sample. The average total trade between two countries is about $32 billion. Bilateral migrant stocks are also significantly different among country-pairs. On average, the sum of bilateral migrants between two countries is 128,121 people.

Table 21 indicates that mobile phones are now more popular than fixed phones. On average, 43 percent of a country's inhabitants have fixed phones, while the number of mobile subscriptions outweighs the number of people. Average Internet usage is also pretty high in the countries in my sample, around 78 percent. The percentage of people who have a broadband connection is much lower, at 28.4 percent.

The next section discusses the empirical results.

3.4 Estimation Results

To empirically estimate the demand for international calling, I implement several models. First, I estimate a least-squares dummy-variables estimator (LSDV) by entering dummies for each country and year. I estimate two different specifications using LSDV: one that is similar to Acton and Vogelsang (1992), and one in which I account for the potential for reciprocal calling and demand persistence by including volume of incoming minutes and lagged outgoing traffic similar to Garin-Munoz and Perez-Amaral (1998), and Karikari and Gyimah-Brempong (1999). Then, I estimate models that deal with endogeneity. To do that, I utilize the Arellano-Bond (DPD) estimator.

Least-Squares Dummy-Variables Estimator. Table 22 presents the results of empirical estimation.[19] Columns (1) and (2) present results of LSDV estimation. The dependent variable is the minutes of outgoing international calls. All variables, except dummy variables, are expressed as logarithms. I start with a simple model similar to Acton and Vogelsang (1992) that doesn't account for reciprocity of telephone calls, i.e. does not include incoming traffic in the current period. The results in column (1) indicate that prices of calls from a landline in the originating country to a landline in the terminating country are negative and significant with the estimated own-price elasticity of demand of -0.24. The price of calls from landlines in the terminating country and price of mobile-to-mobile calls in both directions are insignificant. Thus,

[19]Models (2)-(4) were also estimated under assumption that demand for international telecommunications is persistent. In other words, specifications (2) and (3) also included lagged outgoing traffic and specification (4) included lagged incoming traffic. There was no drastic difference between estimates received under assumption of persisting demand and the ones presented in Table 22.

the results are inconclusive regarding substitutability/complementarity of outgoing and incoming calls. The estimated coefficients of prices of VoIP calls are insignificant.

The estimated coefficient of total trade is positive and significant. The results show that a 10 percent increase in bilateral trade between countries results in a 3.5 percent increase in the volume of outgoing telephone calls. The findings in the existing literature regarding the impact of trade on demand for international calls are conflicting. A significant number of studies find that trade has no impact on the demand for telephone communications between countries.[20] Studies by Karikari and Gyimah-Brempong (1999) and Perkins and Neumayer (2013), on the other hand, find that higher levels of bilateral trade increase the demand for communications between countries. My findings support the results of the latter authors.

The results reveal that higher levels of bilateral migrants between countries result in higher demand for international calls. The impact is equivalent to that of international trade; a 10 percent increase in the stock of bilateral migrants in the country-pair results in the 3.5 percent increase in the volume of outgoing calls.

The estimated coefficient of the penetration of mobile telephones in the originating country is positive and significant. The effect of mobile phone penetration is quite strong, a one percent increase in the penetration rate is estimated to result in the 1.9 percent increase of the volume of telephone calls.

The coefficient of internet penetration is insignificant, indicating that it has no impact on the volume of outgoing international calls. I also find that the levels of GDP per capita in originating and terminating countries have no statistically significant impact. The estimated coefficient of population in the originating country is negative and significant. This result is consistent with several previous studies[21]. One

[20]See, Acton and Vogelsang (1992), Garin-Munoz and Perez-Amaral (1998), and Ford and Jackson (2004).

[21]See, Perkins and Neumayer (2013), Karikari and Gyimah-Brempong (1999).

of the possible explanations for it is that countries with larger populations tend to have higher demand for communications within the country, and lower demand for international calls than less populated countries.

Next, I add the volume of incoming minutes to the previous specification. Outgoing and incoming calls might be substitutes or complements. These two effects are opposites of each other. The sign of the coefficient of incoming calls should indicate which one of these two effects dominates. A positive coefficient would indicate that the reciprocal effect dominates. A negative coefficient of incoming traffic in the current period would indicate that the substitution effect dominates.

The results in column (2) show that the coefficient of minutes of incoming calls is positive and significant indicating that the reciprocal effect is prevalent over substitution effect. The price coefficients replicate the sign and significance of price coefficients in the previous model. The coefficient of the price of calls from fixed phones is negative and significant, and the coefficients of all other prices are insignificant.

The significance and magnitude of other coefficients are very similar to the previous model. Common currency and common official language have a positive and significant impact on international calls, while greater distance between countries results in lower levels of international calls. Higher levels of bilateral trade and migration between country-pairs result in greater consumption of international communications. The results show that higher levels of penetration of fixed phones, mobile phones and the internet in an originating country will also increase the volume of outgoing international traffic. The estimated coefficient of penetration of mobile phones in the terminating country has a negative impact on international calls.

The presence of incoming minutes in the current period might result in an endogeneity problem. If the substitution or reciprocal effects exist, then the volumes of outgoing and incoming traffic might influence each other. The next subsection presents results of Arellano-Bond estimation that addresses endogeneity issue.

Arellano-Bond Estimation. To deal with the potential endogeneity I implement the Arellano and Bond (1991) difference GMM estimator that is appropriate in case of panel data and simultaneous equations model. Columns (3) and (4) display results for two-step Arellano-Bond estimations in which the dependent variables are minutes of outgoing and incoming calls correspondingly. First, the joint test of significance of model (3) rejects the hypothesis that the variation in the dependent variable cannot be explained by the explanatory variables (see F-statistics). The Sargan and Hansen tests of overidentifying restrictions fail to reject the null hypothesis that there is no correlation between the error term and the instrument vector, and indicate that the model is correctly specified.

Now I turn to discussion of the model coefficients. The results show that the coefficient of incoming traffic is negative but insignificant. The results are inconclusive regarding complementarity or substitutability of outgoing and incoming calls.

The coefficients of prices for international calls between fixed phones are insignificant, while the coefficients of prices for international calls over the mobile networks are negative and significant. These results reflect current trends in international and local calling patterns. The majority of the calls are transmitted via wireless networks. I use equations (9) and (10) and estimated coefficients of regression for incoming traffic in column (4) to calculate own- and cross-price elasticities. The estimated own-price elasticity of demand for international calls with respect to mobile price is -0.40. The estimated cross-price elasticity of demand for international calls over wireless networks is -0.29,[22] indicating the complementarity effect between incoming and

[22]The present model is built under assumption that demand for international communications adjusts instantaneously, or does not depend on demand in the previous period. In this case, the short-run elasticity coincides with the long-run elasticity.

outgoing international calls exists. These results are close to the estimated elasticities in Hackl and Westlund (1995) and Madden, Savage and Tipping (2001). Hackl and Westlund (1995) estimate the short-run own-price elasticity of demand in the range of -0.12 to -0.51, and long-run own-price elasticity of demand in the range of -0.37 to -1.8. Madden, Savage and Tipping (2001) estimate that the short-run own-price elasticity of demand varies from -0.18 to -0.46. Karikari and Gyimah-Brempong (1999) find much lower own-price elasticities of demand; the estimated elasticity values are -0.04 in the short-run and -0.12 in the long-run. They also find negative cross-price elasticities of demand for calls from the US to African countries: -0.2 in the short-run and -0.58 in the long-run.

The majority of existing research, except the paper by Perkins and Neumayer (2013), does not include telephone calls transmitted via wireless networks, while Perkins and Neumayer do not include prices in their model. Thus, it is impossible to compare the elasticities for mobile prices to the results in the existing research.

The estimated coefficients of VoIP prices are insignificant, indicating that either the majority of consumers in the sample do not use Skype (the prices of VoIP in the sample are Skype tariffs), or the prices are so low that consumers do not take them into account when they make an international call.

Consistent with the results in the LSDV model, country-pairs with a common official language have higher demand for international calls. The coefficient of common currency is negative and significant. That might be the case because the majority of countries in the sample have different currencies. The results show that the distance between countries, or the sharing of a common border do not have any impact on the demand for international calls.

The results indicate that both total trade and bilateral migration have a positive and significant impact on the demand for international calls. A 10 percent increase in the volume of total trade or the number of bilateral migrants results in approximately 3.6 percent increase in the volume of outgoing calls.

The estimates show that GDP per capita in originating or terminating country, or proliferation of telephones, mobile or fixed, have no significant impact on the number of outgoing calls. Higher levels of fixed broadband adoption result in higher demand for international communications. A 10 percent increase in fixed broadband adoption in the originating country rises the volume of outgoing calls by 11 percent.

The results indicate that larger countries generate more international telephone traffic competing to smaller ones.

Finally, column (4) presents results of Arellano-Bond estimation with the volume of incoming minutes as the dependent variable. The test of joint significance, and Sargan and Hansen tests indicate the correct specification of the model and validity of the instruments.

The results reveal that the coefficient of outgoing traffic is insignificant. This result confirms the hypotheses that substitution and reciprocal effects either offset each other or they are both insignificant. The estimated coefficients of the prices of international calls between fixed phones are insignificant. The prices of international calls between mobile phones from and to terminating country are negative and significant. Negative cross-price effect indicates that complementarity exists between outgoing and incoming calls.

The estimated own-price elasticity of outgoing traffic from terminating country with respect to the price of calls from mobile phones is -0.28; while the estimated cross-price elasticity of outgoing traffic from terminating country with respect to the price of calls from mobile phones in originating country is -0.26.

The estimates show that the price coefficients of VoIP calls are insignificant, confirming the findings of the models (1)-(3).

The results indicate that countries in close proximity and with common official language have higher demand for telephone communications with each other. The estimated coefficient of common currency is negative and significant as in the previous models.

The number of bilateral migrants is also positively associated with the number of incoming minutes in originating country. The estimates suggest that larger countries have higher volumes of incoming traffic. The results reveal that higher proliferation of fixed broadband in terminating country increases demand for international calls.

3.5 Discussion

This paper analyzes the demand for international telephone calls for 24 countries from four world regions for the 2010-2012 period and revisits the estimation of the demand for international calls in light of the newly emerged VoIP technology and the recent changes of consumer preferences towards wireless services.

The analysis examines the significance of landline, mobile and VoIP prices as factors that determine the demand for international communications. The results indicate that the prices of calls from landlines and VoIP do not significantly impact demand for international calls. Conversely, the price of calls from mobile phones has a negative and significant impact on the volume of international calls. The estimated own-price elasticity of demand for calls from mobile phones equals -0.40 for originating calls, and -0.29 for terminating calls. The cross-price elasticity of demand for international calls for mobile service is -0.28 for originating calls and -0.26 for terminating calls. These results are consistent with the estimates in several previous papers.[23] The

[23]See, Hackl and Westlund (1995), Madden, Savage and Tipping (2001), and Karikari and Gyimah-Brempong (1999).

negative cross-price elasticity indicates that incoming and outgoing calls are rather complements than substitutes.

Empirical analysis shows that total trade and migration are important factors that underlie the demand for international calls. The results reveal that higher volumes of trade and larger population of foreign residents drive higher demand for international calls. I find that larger countries have higher demand for international calls than countries with smaller population. The results indicate that the penetration of landlines or mobile phones does not have any impact on the demand for international calls. Higher proliferation of fixed broadband, on the opposite, have positive and significant impact on demand for international communications.

Due to data limitations, it is not possible to separately estimate the demand for international mobile calls or demand for, and degree of substitution between, calls via VoIP and TDM. These issues are important and should be addressed in future research.

FIGURES

FIGURE 1
HOUSEHOLDS WITH WIRELINE, WIRELESS, BOTH OR NONE
2003-2013

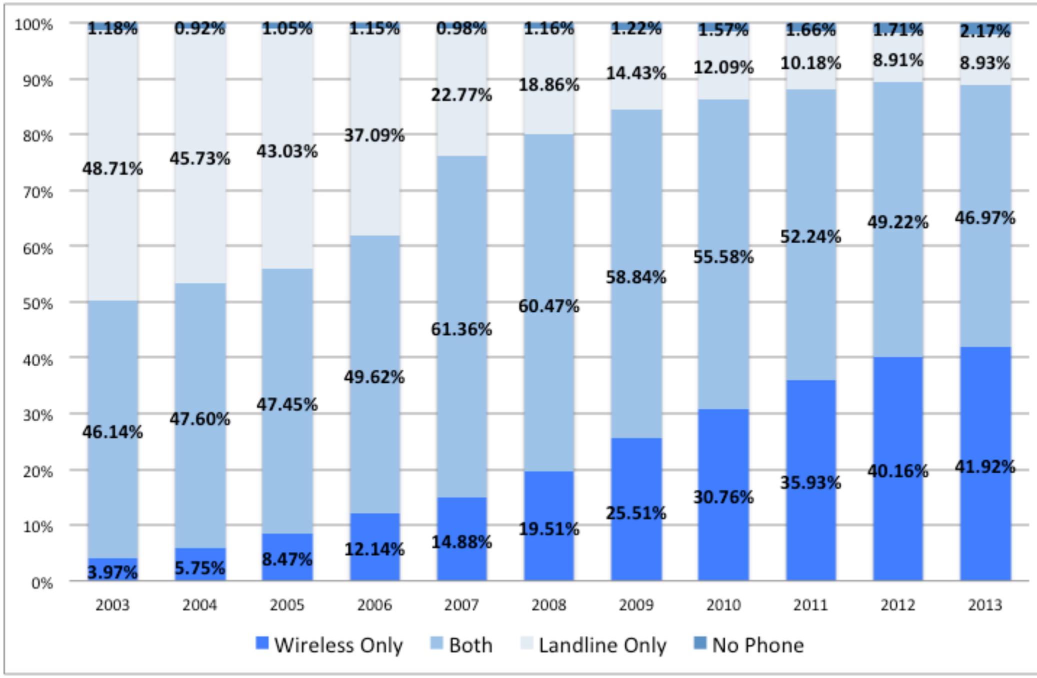


FIGURE 2
HOUSEHOLDS WITH WIRELINE, WIRELESS, BOTH OR NONE
AMONG HOUSEHOLDS BELOW POVERTY THRESHOLD
2003-2013

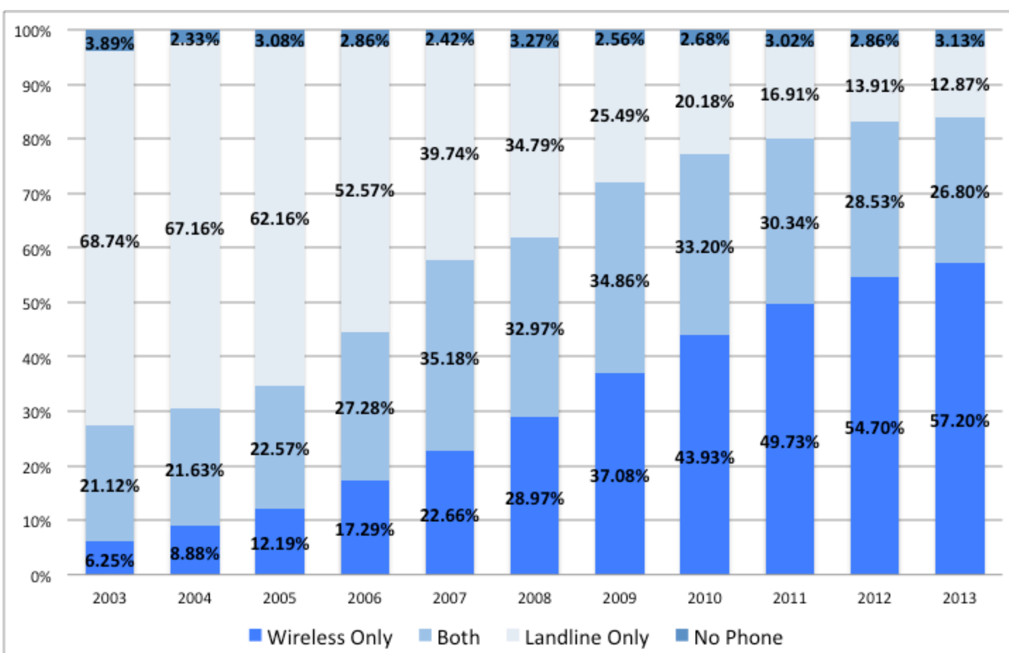


FIGURE 3
HOUSEHOLDS WITH WIRELINE, WIRELESS, BOTH OR NONE
AMONG HOUSEHOLDS WITH ALL MEMBERS UNDER AGE 31
2003-2013

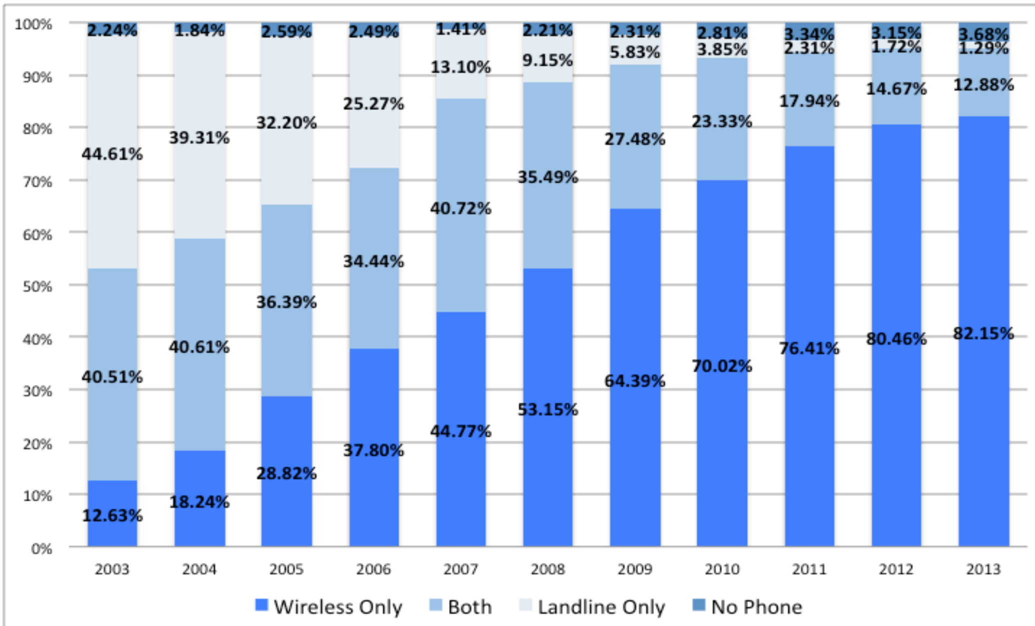
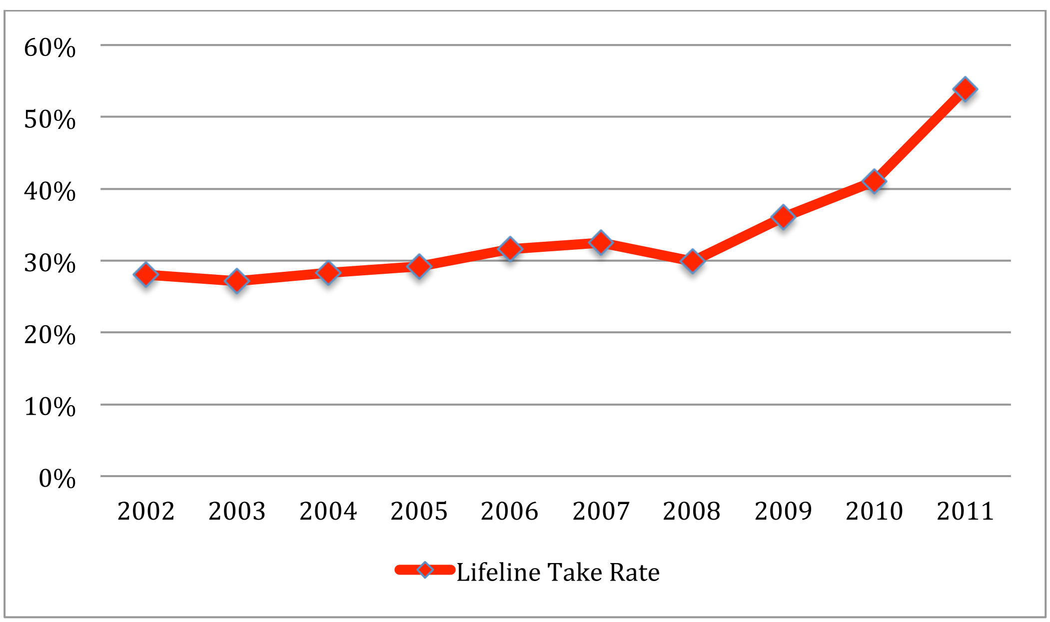
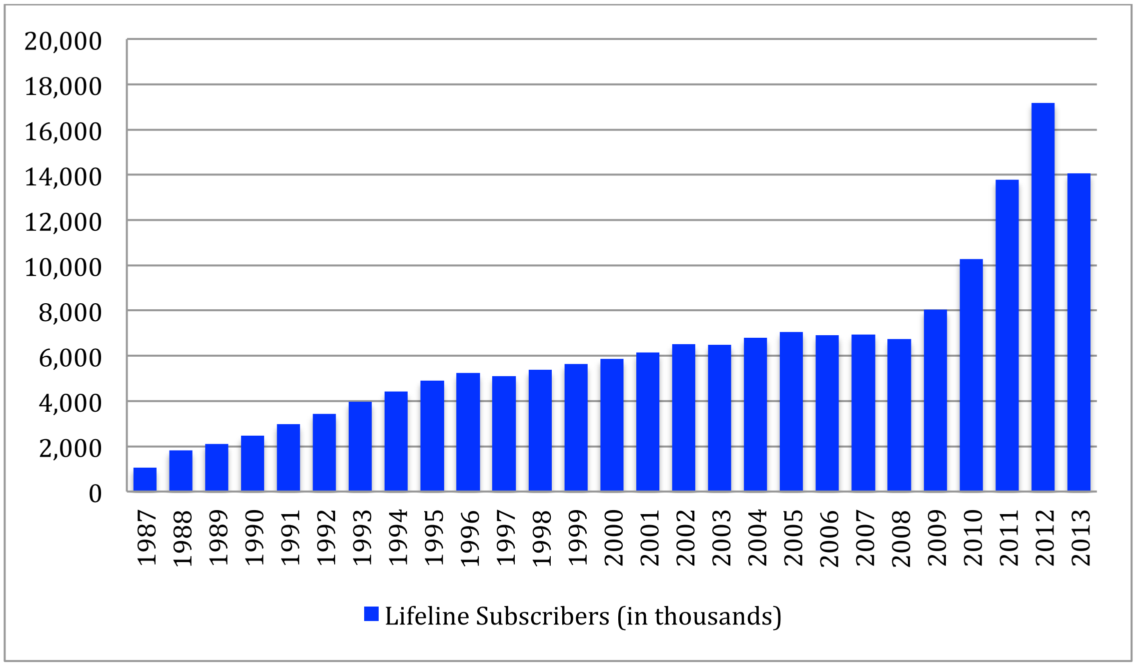


FIGURE 4
LIFELINE TAKE RATES
2002-2011



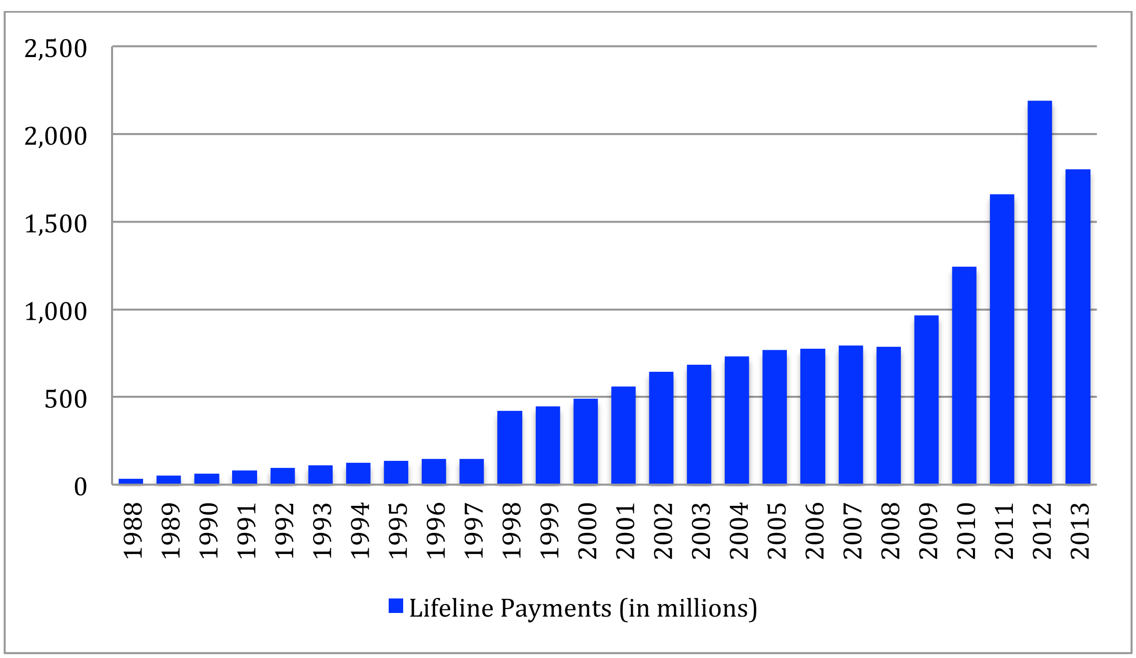
Source: Current Population Survey, 2002-2011;
FCC "Universal Service Monitoring Report", 2012

FIGURE 5
LIFELINE SUBSCRIBERS (IN THOUSANDS)
1987-2013



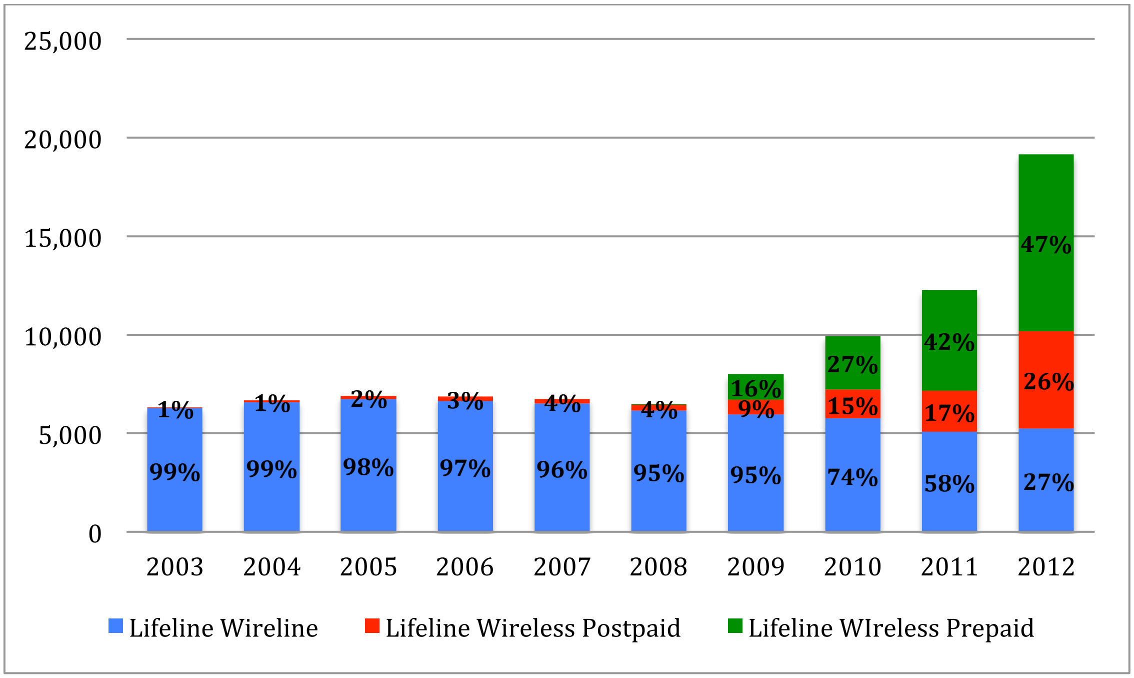
Source: FCC "Universal Service Monitoring Report", 2013
Note: Data on Link Up beneficiaries are missing for year 1997

FIGURE 6
LIFELINE PAYMENTS (IN MILLIONS)
1988-2013



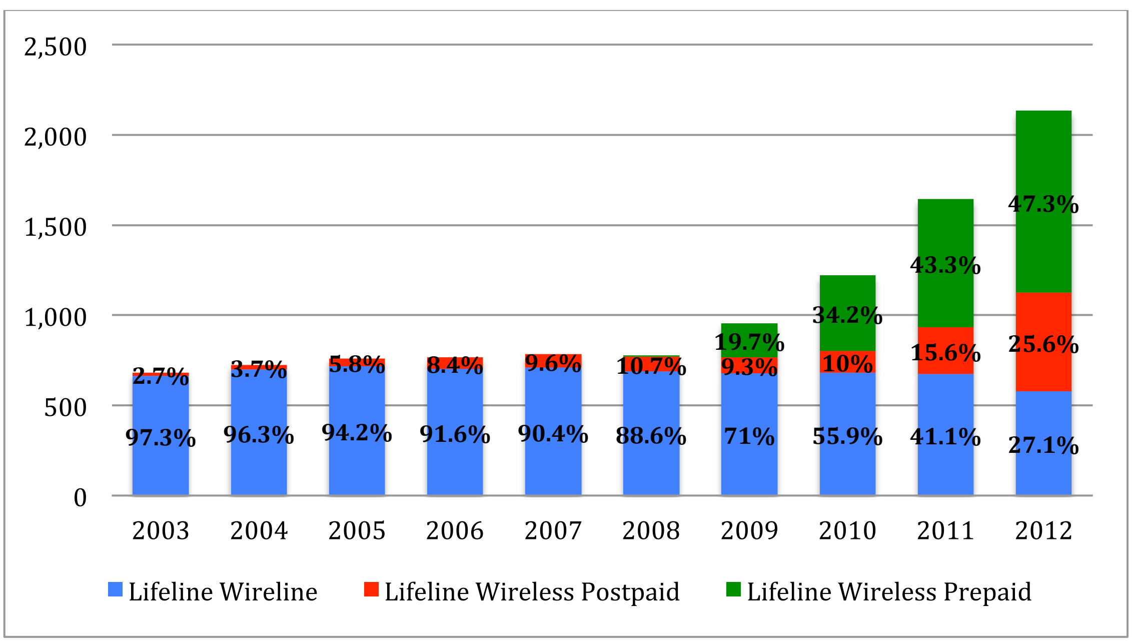
Source: FCC "Universal Service Monitoring Report", 2012

FIGURE 7
LIFELINE SUBSCRIBERS (IN THOUSANDS)
2003-2012



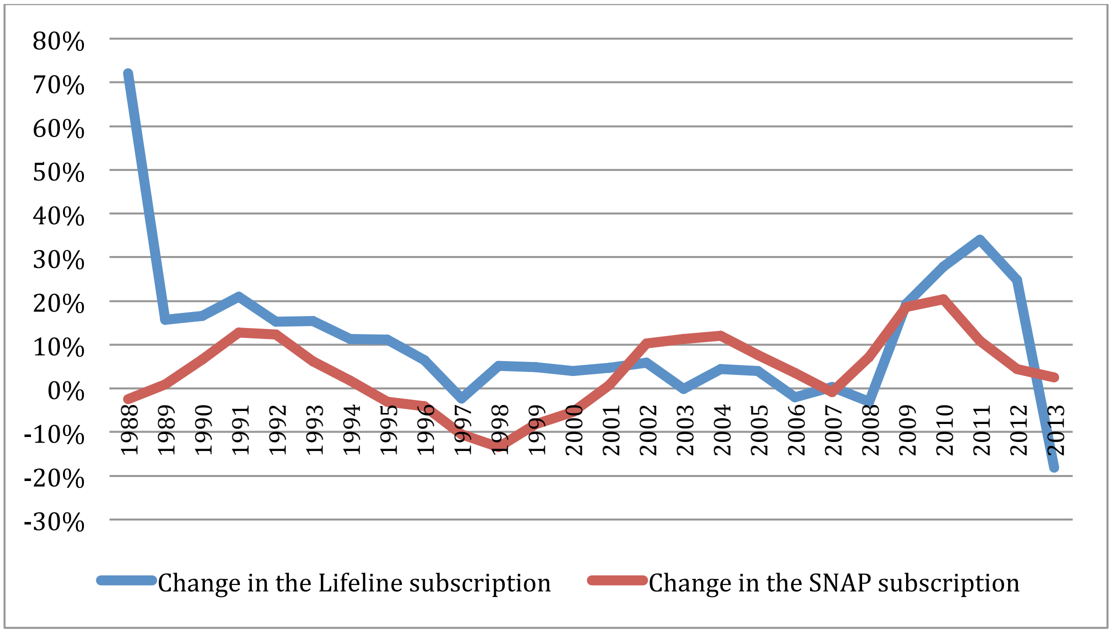
Source: FCC "Universal Service Monitoring Report", 2013

FIGURE 8
LIFELINE PAYMENTS (IN MILLIONS)
2003-2012



Source: FCC "Universal Service Monitoring Report", 2012

FIGURE 9
CHANGES IN LIFELINE SUBSCRIBERS AND SNAP RECEPIENTS (IN THOUSANDS)
1988-2013



Source: FCC "Universal Service Monitoring Report", 2012
http://www.fns.usda.gov/pd/SNAPsummary.htm

FIGURE 10
HOUSEHOLD SUBSCRIBERSHIP TO THE TELEPHONE SERVICE
2003-2011

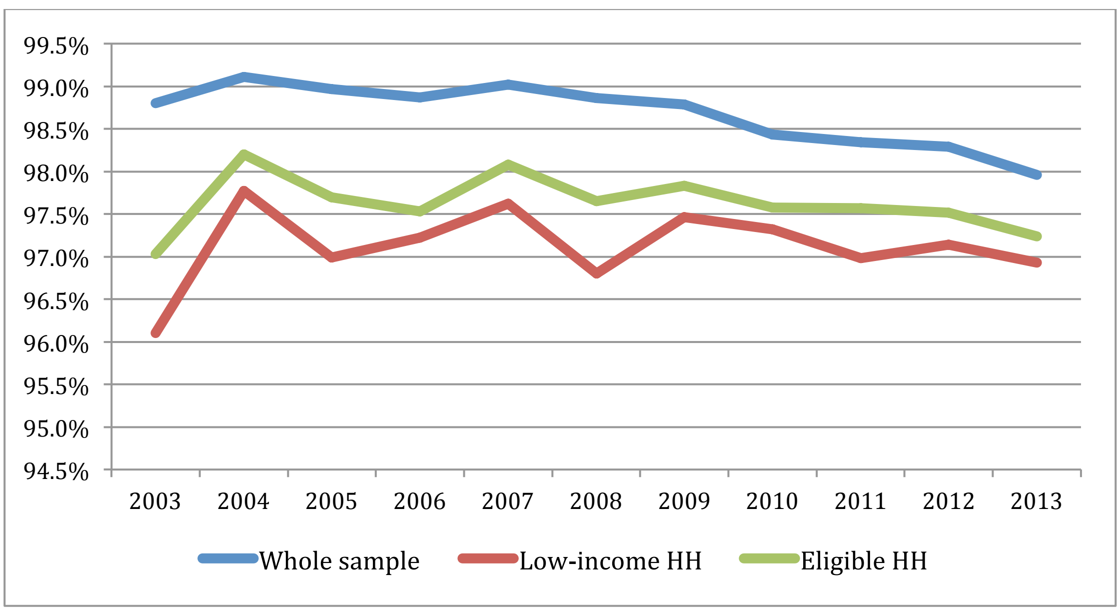


FIGURE 11
ELIGIBLE HOUSEHOLDS WITH WIRELESS, BOTH WIRELINE OR NONE
2003-2013

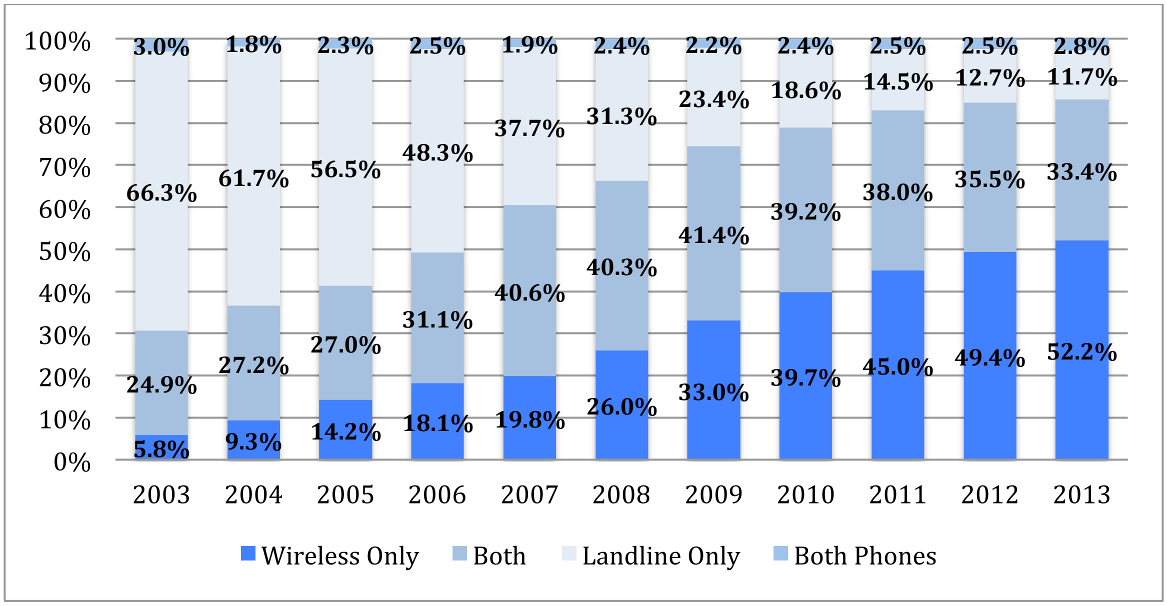
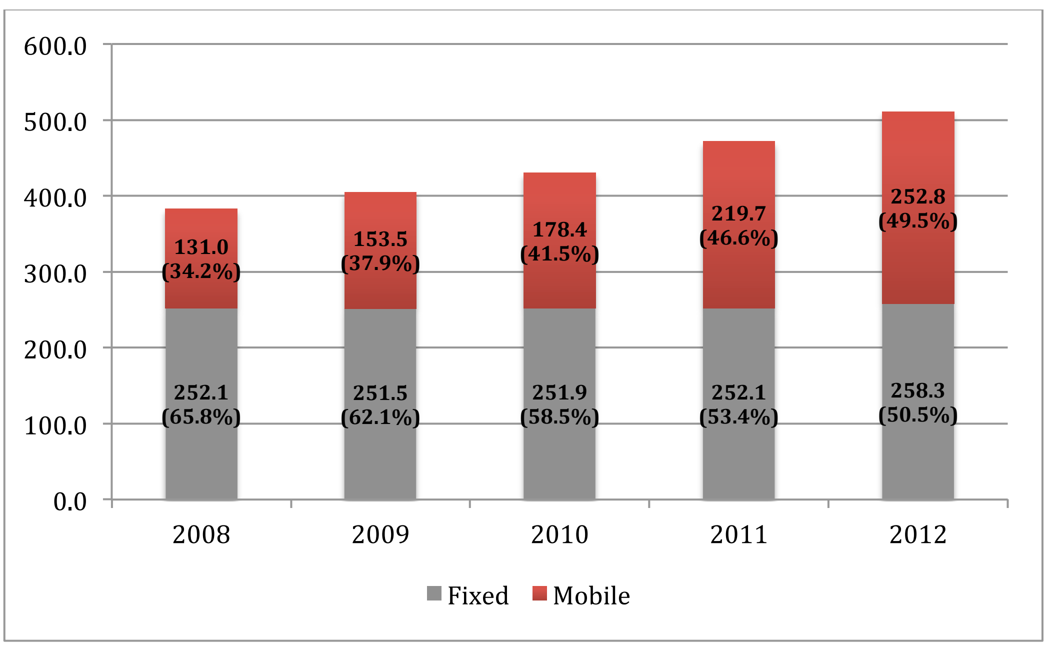
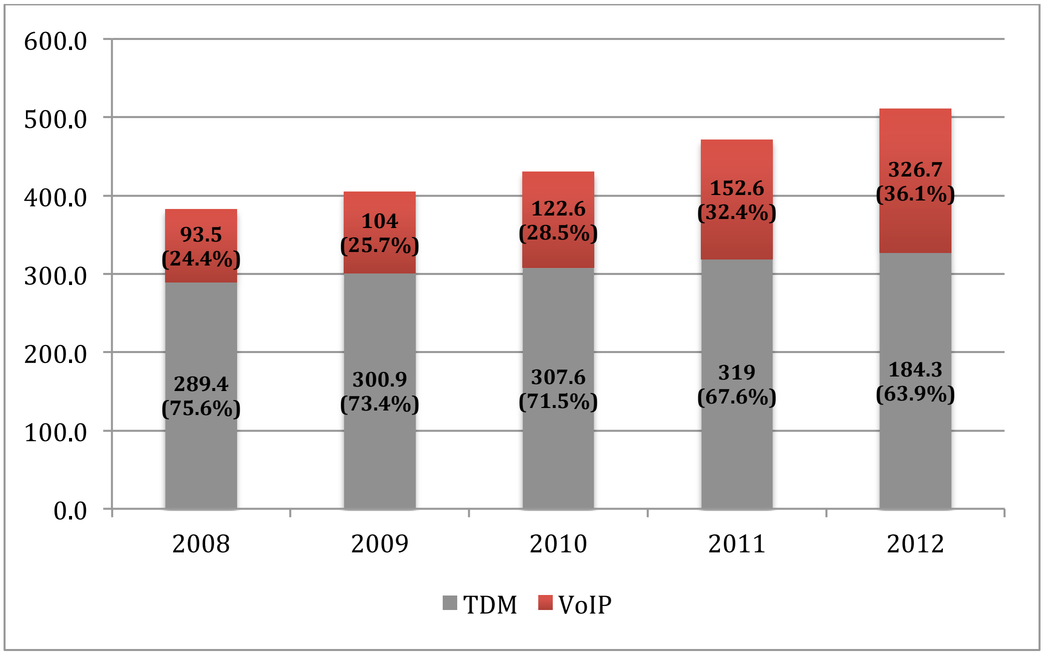


FIGURE 12
INTERNATIONAL ORIGINATED TRAFFIC (IN BILLION)
2008-2012



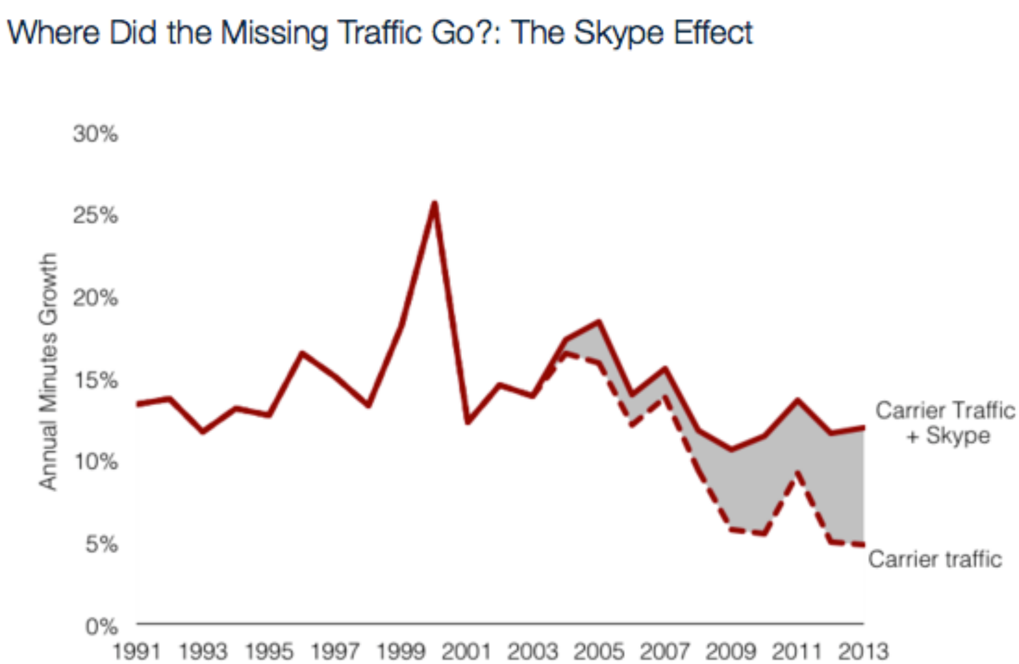
Source: TeleGeography Report, 2013

FIGURE 13
INTERNATIONAL ORIGINATED TRAFFIC (IN BILLION)
2008-2012



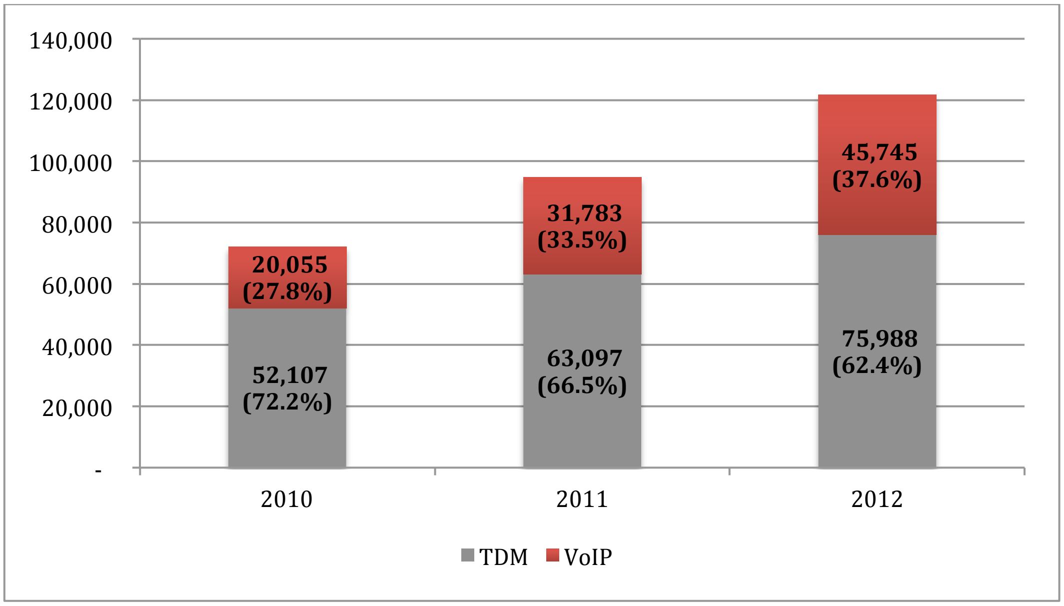
Source: TeleGeography Report, 2013

FIGURE 14
SKYPE EFFECT



Source: TeleGeography report, 2013.

FIGURE 15
INTERNATIONAL ORIGINATED TRAFFIC (IN MILLION)
FOR THE SAMPLE USED IN ESTIMATION
2010-2012



Source: TeleGeography report, 2013.

Tables

TABLE 1
WIRELINE AND WIRELESS CONSUMPTION

Whole Sample		
Phone	Frequency	Percent
None	2,228	1.18%
Wireline Only	56,141	29.61%
Wireless Only	29,831	15.73%
Both	101,416	53.48%
Whole Sample	189,616	100.00%

TABLE 2
TETRACHORIC AND PARTIAL CORRELATIONS FOR WIRELINE AND WIRELESS CONSUMPTION

	Tetrachoric Correlation	Partial correlation
Full Sample	-0.5328*	-0.3720*
Year 2003	-0.3384*	0.0507*
Year 2004	-0.4651*	-0.0562*
Year 2005	-0.5196*	-0.1343*
Year 2006	-0.5457*	-0.2001*
Year 2007	-0.4519*	-0.138
Year 2008	-0.4452*	-0.1798*
Year 2009	-0.4433*	-0.1888*
Year 2010	-0.4098*	-0.2268*
Income1	-0.7187*	-0.6631*
Income2	-0.6836*	-0.6013*
Income3	-0.5724*	-0.4864*
Income4	-0.3859*	-0.4164*

*Significant at 1 percent.

TABLE 3
PARAMETER ESTIMATES FOR PROBIT AND BIVARIATE PROBIT MODELS

	Model (a)		Model (b)	
	Probit		Bivariate probit	
VARIABLES	***wireline***	***wireless***	***wireline***	***wireless***
Wireless				
Price				
Wireline Price	-0.0134*	0.0372***	-0.0101	0.0367***
	(0.00748)	(0.00607)	(0.00743)	(0.00606)
Wireless Price	0.0849***	-0.0611***	0.0826***	-0.0611***
	(0.00376)	(0.00295)	(0.00373)	(0.00294)
Income				
Income2	-0.0108	0.242***	-0.00989	0.240***
	(0.01480)	(0.01230)	(0.01480)	(0.01230)
Income3	0.137***	0.550***	0.120***	0.546***
	(0.01380)	(0.01170)	(0.01380)	(0.01170)
Income4	0.369***	0.859***	0.342***	0.849***
	(0.01530)	(0.01340)	(0.01530)	(0.01340)
Nodal				
Retired Household	0.465***	-0.168***	0.439***	-0.170***
	(0.02650)	(0.01820)	(0.02590)	(0.01820)
Young Household	-0.793***	0.432***	-0.795***	0.443***
	(0.01240)	(0.01230)	(0.01240)	(0.01230)
Young-Middle Household	-0.398***	0.264***	-0.411***	0.266***
	(0.01790)	(0.01640)	(0.01780)	(0.01640)
Older-Middle Household	0.0753***	0.0751***	0.0530***	0.0684***
	(0.01660)	(0.01290)	(0.01650)	(0.01290)
Student	-0.0786***	0.318***	-0.0617***	0.313***
	(0.01990)	(0.01810)	(0.02000)	(0.01800)
Housewife	0.0242	-0.00908	0.0129	-0.00926
	(0.01520)	(0.01180)	(0.01500)	(0.01170)
Part-Time Employed	0.146***	0.129***	0.142***	0.127***
	(0.01340)	(0.01160)	(0.01330)	(0.01160)
Ratio Working	-0.439***	0.397***	-0.423***	0.399***
	(0.02240)	(0.01750)	(0.02200)	(0.01750)
Limited Youth	0.000195	0.109***	-0.00185	0.108***
	(0.01510)	(0.01270)	(0.01490)	(0.01260)
Limited Adult	0.0877***	-0.0501***	0.0860***	-0.0495***
	(0.01570)	(0.01130)	(0.01540)	(0.01130)
Own House	0.538***	0.101***	0.528***	0.0941***
	(0.01040)	(0.00895)	(0.01040)	(0.00897)
Children	-0.125***	0.404***	-0.136***	0.398***
	(0.01950)	(0.01580)	(0.01940)	(0.01580)
Wealthy Retired Household	-0.156***	0.204***	-0.150***	0.209***
	(0.03470)	(0.01900)	(0.03470)	(0.01900)
Population Density	4.21e-06**	-1.25e-05***	3.51e-06*	-1.24e-05***
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Quality controls				
Wireline Broadband	1.219***	-0.374***	1.157***	-0.395***
	(0.09780)	(0.07870)	(0.09700)	(0.07880)
Cellsites	-2.19e-05***	1.41e-05***	-2.13e-05***	1.42e-05***
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Wireline Price Residual	0.00702	-0.0304***	0.00371	-0.0299***
	(0.00750)	(0.00609)	(0.00745)	(0.00608)
Wireless Price Residual	-0.0519***	0.0391***	-0.0508***	0.0390***
	(0.00387)	(0.00304)	(0.00385)	(0.00303)
Rho (ρ)				-0.523***
				(0.00750)
Demographic controls	yes	yes	yes	yes
Other quality controls	yes	yes	yes	yes
Constant				
Observations	185,911	185,911	185,911	185,911

*Significant at 10 percent

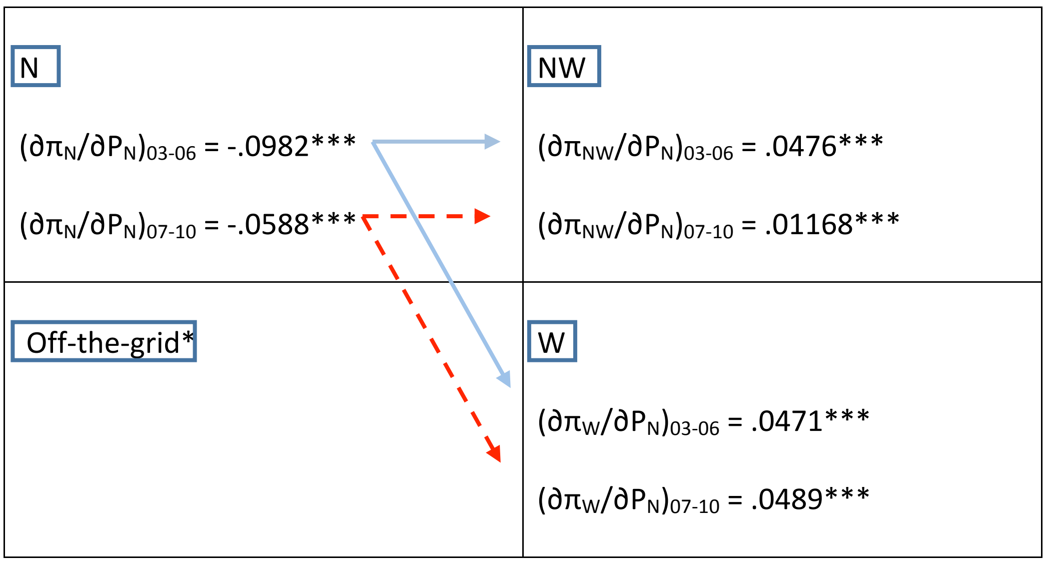
**Significant at 5 percent
***Significant at 1 percent.

TABLE 4
MARGINAL PRICE AND INCOME EFFECTS ON CONSUMER CHOICES

	Wireline	***Wireless***
Own	$(\partial Q_N/\partial P_N)$ = -.0019***	$(\partial Q_W/\partial P_W)$ = -.0204***
Cross	$(\partial Q_N/\partial P_W)$ = .0152***	$(\partial Q_W/\partial P_N)$ = .0122***
Change from Income1 to Income4	$Q_N^{Income4} - Q_N^{Income1}$ = .0595***	$Q_W^{Income4} - Q_W^{Income1}$ = .2577***

***Significant at 1 percent.

TABLE 5
THE EVOLUTION OF CONSUMER SUBSTITUTION PATTERNS



*The marginal impact of wireline prices on the likelihood of consumers shifting to the "off the grid" category is estimated to be essentially zero and is not shown here.
***Significant at 1 percent.

TABLE 6

PARAMETER ESTIMATES FOR MIXED LOGIT MODEL

VARIABLES	***both***	***land***	***wireless***
Price		-0.013***	
		(0.002)	
*Price*Income2*		-0.003	
		(0.002)	
*Price*Income3*		0.001	
		(0.002)	
*Price*Income4*		0.002	
		(0.002)	
Price Residual		0.007***	
		(0.002)	
Income			
Income2	0.87***	0.29***	0.62***
	(0.230)	(0.079)	(0.180)
Income3	1.32***	0.38***	0.71***
	(0.218)	(0.083)	(0.173)
Income4	1.96***	0.40***	0.84***
	(0.230)	(0.098)	(0.184)
Demographic characteristics			
Retired Household	0.66***	1.08***	-0.46***
	(0.105)	(0.105)	(0.1124)
Young Household	-0.55***	-0.89***	0.72***
	(0.064)	(0.065)	(0.065)
Young-Middle Household	-0.36***	-0.55***	0.17*
	(0.092)	(0.092)	(0.093)
Older-Middle Household	-0.02	-0.02	-0.32***
	(0.080)	(0.080)	(0.083)
Student	0.78***	0.32***	0.75***
	(0.107)	(0.108)	(0.109)
Housewife	0.06	0.17**	-0.12
	(0.076)	(0.076)	(0.078)
Part-Time Employed	0.63***	0.36***	0.34***
	(0.087)	(0.088)	(0.088)
Ratio Working	0.28***	-0.08	0.70***
	(0.089)	(0.089)	(0.091)
Limited Youth	0.29***	0.06	0.19**
	(0.093)	(0.093)	(0.095)
Limited Adult	0.05	0.25***	-0.17**
	(0.075)	(0.075)	(0.078)
Own House	1.08***	0.75***	-0.01
	(0.058)	(0.058)	(0.059)
Children	0.22***	0.0398	0.14***
	(0.030)	(0.030)	(0.031)
Wealthy Retired Household	0.00	-0.17	0.03
	(0.232)	(0.233)	(0.245)
Population Density	0.00	0.00***	-0.01***
	(0.002)	(0.002)	(0.002)
Quality Controls			
Wireline Broadband	0.21	0.10	-1.32***
	(0.255)	(0.259)	(0.257)
Cellsites	0.06	-0.66**	3.49***
	(0.263)	(0.264)	(0.273)
Other Demographic Controls	*Yes*	*Yes*	*Yes*
Other Quality Controls	*Yes*	*Yes*	*Yes*
Year Dummies	*Yes*	*Yes*	*Yes*
Constant	4.044***	4.04***	-4.36***
	(0.418)	(0.418)	(0.472)
Observations	167,345	167,345	167,345

*Significant at 10 percent
*Significant at 10 percent
**Significant at 5 percent
***Significant at 1 percent.

TABLE 7
AMOUNT OF LIFELINE SUPORT PER STATE, 2012

State	***Total Lifeline Support***
Alabama	$9.67
Alaska	9.79
American Samoa	8.71
Arizona	9.36
Arkansas	9.10
California	8.84
Colorado	9.50
Connecticut	9.12
Delaware	9.60
District of Columbia	8.42
Florida	9.61
Georgia	9.61
Guam	8.75
Hawaii	8.80
Idaho	9.63
Illinois	8.79
Indiana	9.21
Iowa	8.75
Kansas	9.06
Kentucky	9.58
Louisiana	9.60
Maine	9.55
Maryland	9.21
Massachusetts	9.61
Michigan	9.19
Minnesota	8.92
Mississippi	9.59
Missouri	9.13
Montana	9.18

State	***Total Lifeline Support***
Nebraska	8.85
Nevada	8.75
New Hampshire	9.40
New Jersey	9.51
New Mexico	9.60
New York	9.59
North Carolina	9.52
North Dakota	9.25
Northern Mariana Islands	9.44
Ohio	9.29
Oklahoma	8.88
Oregon	9.65
Pennsylvania	9.14
Puerto Rico	9.72
Rhode Island	9.55
South Carolina	9.59
South Dakota	8.73
Tennessee	9.57
Texas	9.27
Utah	9.59
Vermont	9.58
Virgin Islands	10.80
Virginia	9.40
Washington	9.27
West Virginia	9.66
Wisconsin	9.02
Wyoming	9.75
Average	***$9.32***

Source: FCC “Universal Service Monitoring Report”, 2013

TABLE 8
PERCENT OF HOUSEHOLDS WITHOUT TELEPHONE SERVICE,
2003-2010

Year	*Full NHIS sample*	*Sample used for estimation*
2003	3.59%	1.27%
2004	3.48%	0.93%
2005	3.52%	1.16%
2006	3.82%	1.17%
2007	2.90%	0.91%
2008	2.87%	1.13%
2009	2.52%	1.20%
2010	2.64%	1.52%

Note: Statistics for this table is based on the whole NHIS sample. Sample used for estimation is restricted to households for which all information is available.

TABLE 9
COMPARISON OF PENETRATION RATES BY LEVEL OF LIFELINE ASSISTANCE

		Low-Income Households				*All Households*			
Lifeline Category	#	Mar-97	Mar-11	Change	Change per Year	Mar-97	Mar-11	Change	Change per Year
Full or High Assistance	33	85.6%	90.7%	5.1%	0.36%	93.7%	95.4%	1.8%	0.13%
Intermediate Assistance	14	87.2%	94.1%	6.9%	0.49%	95.0%	97.4%	2.3%	0.17%
Basic or Low Assistance	4	86.2%	89.1%	2.9%	0.21%	93.9%	95.1%	1.2%	0.08%

Source: FCC "Universal Service Monitoring Report", 2012

TABLE 10
PERCENT OF HOUSEHOLDS WITH NO PHONE, WIRELINE, WIRELESS, OR BOTH
2003-2010

Year	*No Phone*	*Landline*	*Wireless*	*Both*	*Number of Households*
2003	1.27%	48.28%	4.15%	46.31%	20,650
2004	0.93%	44.38%	6.18%	48.51%	20,913
2005	1.16%	41.71%	9.03%	48.10%	22,082
2006	1.17%	35.96%	12.97%	49.90%	16,711
2007	0.91%	21.77%	15.97%	61.36%	19,127
2008	1.13%	18.01%	20.71%	60.15%	19,273
2009	1.20%	13.79%	26.46%	58.55%	23,852
2010	1.52%	11.50%	31.82%	55.16%	24,789

TABLE 11
DESCRIPTIVE STATISTICS
2003-2010

Demographic Variables and	*Percent*
Income Groups	
Income1	14.93%
Income2	19.27%
Income3	29.62%
Income4	39.19%
Own Home	62.50%
Household Size	
1 person	25.56%
2 people	31.47%
3 people	16.61%
4 people	14.88%
5 or more people	11.48%
Mean Number of Children	0.74
Chosen Phone Option	
No Phone	1.17%
Landline Only	28.82%
Wireless Only	16.46%
Both	53.54%
Eligible Households	24.24%
Black	14.67%
Hispanic	16.46%
Native American	0.67%
Wireline Price	$16.81
Wireless Price	$58.55
Lifeline benefit	$11.48

TABLE 12
PARAMETER ESTIMATES FOR MIXED LOGIT MODEL
(PERFECT ENFORCEMENT)

VARIABLES		***Coefficients***	
Price		-0.007***	
		(0.0029)	
*Price*Income2*		-0.011***	
		(0.0031)	
*Price*Income3*		-0.004	
		(0.0029)	
*Price*Income4*		-0.003	
		(0.0030)	
Price Residual		0.000	
		(0.0021)	
Low Income Program			
Lifeline Benefit x Eligible		0.08*	
		(0.0507)	
Lifeline Benefit Residual		-0.11*	
		(0.0507)	
sd.price		0.003	
		(0.0040)	
	both	***land***	***wireless***
Prepaid Wireless Lifeline Payments	0.004	0.005*	0.03***
x Eligible	(0.0031)	(0.0032)	(0.0031)

Income			
Income2	1.31***	0.42***	-0.13
	(0.2468)	(0.0889)	(0.1936)
Income3	1.33***	0.38***	-0.83***
	(0.2429)	(0.1054)	(0.1952)
Income4	1.74***	0.26**	-0.90***
	(0.2545)	(0.1206)	(0.2073)
Demographic characteristics			
Retired Household	0.45***	0.64***	-0.24**
	(0.1012)	(0.1010)	(0.1076)
Age of Reference Person	0.01***	0.02***	-0.01***
	(0.0015)	(0.0015)	(0.0016)
Own House	1.02***	0.69***	-0.17***
	(0.0572)	(0.0573)	(0.0584)
Black Household	-0.12*	-0.06	-0.34***
	(0.0655)	(0.0657)	(0.0675)
Hispanic Household	-0.57***	-0.21***	-0.42***
	(0.0609)	(0.0609)	(0.0621)
Native American Household	-0.72***	-0.64***	-0.58***
	(0.1724)	(0.1733)	(0.1785)
Population Density	0.06***	0.03**	-0.03**
	(0.015)	(0.0148)	(0.0149)
Household Size	0.24***	0.05	-0.03
	(0.0355)	(0.0356)	(0.0361)
Male Household	-0.79**	-0.50***	-0.02
	(0.0603)	(0.0602)	(0.0612)
Educated Household	0.43***	0.13*	0.16**
	(0.0694)	(0.0699)	(0.0706)
Ratio Working	0.17**	-0.21***	0.68***
	(0.0795)	(0.0790)	(0.0820)
Limited Youth	0.33***	0.11	0.28***
	(0.0928)	(0.0930)	(0.0955)
Student	0.48***	0.17	0.58***
	(0.1082)	(0.1094)	(0.1107)
Children	0.07	0.15***	0.05
	(0.0468)	(0.0470)	(0.0478)
Eligible	-1.33**	-1.05*	-3.77***
	(0.5942)	(0.5937)	(0.5950)
Quality Control			
Cell Sites	0.32	-1.02***	4.29***
	(0.3445)	(0.3400)	(0.3706)
Constant	-2.43	14.44***	-47.53***
	(4.1543)	(4.0872)	(4.4704)
Year Dummies	*yes*	yes	yes
State Dummies	*no*	no	no
Observations	167,397	167397	167397

Note: The reference category is "no phone." The exclusion restrictions used in the first stage are: *Hausman-Type Instrument, Mobile Penetration, and Democrat Governor.*

*Significant at 10 percent
**Significant at 5 percent
***Significant at 1 percent.

TABLE 13
ACTUAL AND PREDICTED FREQUENCES OF ALTERNATIVES (PERCENT)

	No Phone	*Both*	*Landline Only*	*Wireless Only*
Actual Shares	1.174%	53.544%	28.821%	16.460%
Predicted Shares	1.175%	53.544%	28.822%	16.460%

TABLE 14
EFFECTS OF PRICE/POLICY CHANGES (NUMBER OF HOUSEHOLDS)

Policy Change	*No Phone*	*Both*	*Landline Only*	*Wireless Only*
Turn Off Wireless Lifeline Initiative	147,034	988,944	616,658	-1,752,635
Turn Off Lifeline and Wireless Lifeline Initiative	1,080,055	-117,325	-334,431	-628,297

TABLE 15
PARAMETER ESTIMATES FOR MIXED LOGIT MODEL
(INEFFECTIVE ENFORCEMENT)

VARIABLES		***Coefficients***	
Price		-0.015***	
		(0.0031)	
*Price*Income2*		-0.007**	
		(0.0033)	
*Price*Income3*		0.001	
		(0.0031)	
*Price*Income4*		0.003	
		(0.0032)	
Price Residual		0.007***	
		(0.0021)	
Low Income Program			
Lifeline Benefit		0.02***	
		(0.0028)	
Lifeline Benefit Residual		-0.06***	
		(0.0028)	
sd.price		-0.00	
		(0.0055)	
	both	***land***	***wireless***
Prepaid Wireless Lifeline Payments	0.01***	0.008***	0.01***
	(0.0025)	(0.0026)	(0.0026)
Income			
Income2	1.05***	0.36***	-0.85***
	(0.2607)	(0.0908)	(0.2046)
Income3	0.91***	0.28***	-1.73***
	(0.2555)	(0.1068)	(0.2047)
Income4	1.24***	0.14	-1.86***
	(0.2664)	(0.1218)	(0.2162)
Demographic characteristics			
Retired Household	0.428***	0.63***	-0.32***
	(0.1011)	(0.1009)	(0.1080)
Age of Reference Person	0.01***	0.02***	-0.01***
	(0.0015)	(0.0015)	(0.0016)
Own House	1.02***	0.69***	-0.19***
	(0.0569)	(0.0572)	(0.0584)
Black Household	-0.11*	-0.05	-0.31***
	(0.0648)	(0.0650)	(0.0672)
Hispanic Household	-0.57***	-0.21***	-0.45***
	(0.0603)	(0.0606)	(0.0623)
Native American Household	-0.73***	-0.65***	-0.62***
	(0.1719)	(0.1730)	(0.1829)
Population Density	0.08***	0.04**	-0.00
	(0.0150)	(0.0149)	(0.0150)
Household Size	0.24***	0.05	-0.03
	(0.0354)	(0.0356)	(0.0362)
Male Household	-0.80**	-0.50***	-0.02
	(0.0602)	(0.0602)	(0.0615)
Educated Household	0.43***	0.13*	0.14**
	(0.0692)	(0.0699)	(0.0706)
Ratio Working	0.15**	-0.23***	0.58***

	(0.0788)	(0.0788)	(0.0824)
Limited Youth	0.33***	0.11	0.31***
	(0.0926)	(0.0930)	(0.0963)
Student	0.45***	0.16	0.51***
	(0.1077)	(0.1090)	(0.1113)
Children	0.07	0.14***	0.02
	(0.0468)	(0.0470)	(0.0482)
Eligible	-0.31***	-0.04	-3.76***
	(0.0761)	(0.0765)	(0.0815)
Quality Control			
Cell Sites	0.22	-1.07***	4.22***
	(0.3377)	(0.3354)	(0.3676)
Constant	-1.18	14.77***	-45.76***
	(4.0707)	(4.0309)	(4.4338)
Year Dummies	yes	yes	yes
State Dummies	no	no	no
Observations	167397	167397	167397

Note: The reference category is "no phone." The exclusion restrictions used in the first stage are: *Hausman-Type Instrument, Mobile Penetration, and Families Below 135.*

*Significant at 10 percent
**Significant at 5 percent
***Significant at 1 percent.

TABLE 16
ACTUAL AND PREDICTED FREQUENCES OF ALTERNATIVES (PERCENT)

	No Phone	*Both*	*Landline Only*	*Wireless Only*
Actual Shares	1.174%	53.544%	28.821%	16.460%
Predicted Shares	1.174%	53.544%	28.821%	16.460%

TABLE 17
EFFECTS OF PRICE/POLICY CHANGES (NUMBER OF HOUSEHOLDS)

Policy Change	*No Phone*	*Both*	*Landline Only*	*Wireless Only*
Turn Off Wireless Lifeline Initiative	76,001	409,361	146,434	-631,796
Turn Off Lifeline and Wireless Lifeline Initiative	401,911	-1,820,017	-778,514	2,196,622

APPENDIX A

COMPARISON OF NHIS AND THE US CENSUS BUREAU DEMOGRAPHICS

	General Demographic Characteristics: July 2006	NHIS Sample 2006	General Demographic Characteristics: July 2007	NHIS Sample 2007	General Demographic Characteristics: July 2008	NHIS Sample 2008	General Demographic Characteristics: July 2009	NHIS Sample 2009
SEX AND AGE								
Male	49.27%	48.28%	49.29%	48.35%	49.31%	48.35%	49.33%	48.19%
Female	50.73%	51.72%	50.71%	51.65%	50.69%	51.65%	50.67%	51.81%
Under 5 years	6.82%	7.37%	6.87%	7.71%	6.91%	7.50%	6.94%	7.37%
5 to 9 years	6.58%	7.79%	6.58%	7.79%	6.60%	7.70%	6.71%	7.90%
10 to 14 years	6.89%	7.69%	6.74%	7.81%	6.60%	7.50%	6.51%	7.65%
15 to 19 years	7.12%	7.46%	7.12%	7.54%	7.08%	7.38%	7.02%	7.50%
20 to 24 years	7.05%	6.63%	6.97%	6.49%	6.93%	6.50%	7.02%	6.19%
25 to 34 years	13.50%	13.29%	13.46%	13.31%	13.46%	13.47%	13.54%	13.15%
35 to 44 years	14.58%	14.64%	14.31%	14.44%	13.98%	14.01%	13.53%	13.89%
45 to 54 years	14.46%	14.06%	14.55%	14.14%	14.59%	14.22%	14.52%	14.28%
55 to 59 years	6.09%	5.66%	6.05%	5.54%	6.11%	5.95%	6.18%	5.91%
60 to 64 years	4.46%	4.31%	4.80%	4.34%	4.97%	4.63%	5.15%	5.05%
65 to 74 years	6.32%	6.10%	6.42%	6.04%	6.62%	6.10%	6.77%	6.26%
75 to 84 years	4.36%	3.77%	4.32%	3.72%	4.28%	3.84%	4.28%	3.67%
85 years and over	1.77%	1.22%	1.83%	1.13%	1.88%	1.21%	1.83%	1.18%
Median age (years)	36.4	34	36.6	34	36.8	34	36.8	35
18 years and over	75.37%	72.39%	75.50%	71.85%	75.68%	72.68%	75.72%	72.36%
21 years and over	71.18%	68.36%	71.31%	67.86%	71.43%	68.61%	71.41%	68.34%
62 years and over	15.08%	13.48%	15.24%	13.25%	15.41%	13.57%	15.79%	14.00%
65 years and over	12.45%	11.09%	12.56%	10.89%	12.78%	11.15%	12.89%	11.11%
18 years and over	75.37%	72.39%	75.50%	71.85%	75.68%	72.68%	75.72%	72.36%
Male	36.67%	34.25%	36.75%	33.89%	36.86%	34.33%	36.91%	34.04%
Female	38.71%	38.14%	38.75%	37.96%	38.82%	38.35%	38.81%	38.32%
65 years and over	12.45%	11.09%	12.56%	10.89%	12.78%	11.15%	12.89%	11.11%
Male	5.23%	4.80%	5.30%	4.73%	5.41%	4.77%	5.48%	4.90%
Female	7.22%	6.29%	7.26%	6.16%	7.37%	6.38%	7.41%	6.20%
RACE								
White	80.08%	66.94%	79.96%	67.29%	79.80%	66.62%	79.57%	66.15%
Black or African American	12.81%	16.18%	12.85%	15.51%	12.85%	15.59%	12.91%	15.75%
American Indian and Alaska Native	0.97%	0.89%	0.97%	1.16%	1.01%	1.10%	1.03%	0.81%
Asian	4.40%	6.35%	4.43%	5.88%	4.46%	6.30%	4.56%	6.41%
HISPANIC OR								
Hispanic or Latino (of any race)	14.80%	23.59%	15.09%	24.64%	15.44%	23.85%	15.77%	25.34%
Not Hispanic or Latino Total	85.20%	76.41%	84.91%	75.36%	84.56%	76.15%	84.23%	74.66%

Table 19: Traffic by Country, 2012.

Country	Outgoing Traffic (percent)	Incoming Traffic (percent)
Austria	0.54	0.39
Belgium	0.87	0.61
Brazil	0.38	1.8
Canada	3.34	3.18
Czech Republic	0.22	0.18
Denmark	0.36	0.22
Finland	0.13	0.09
France	3.69	2.68
Germany	5.02	2.69
Hong Kong	3.63	1.52
India	3.86	7.27
Ireland	0.47	0.48
Italy	2.5	1.6
Japan	2.33	0.71
Netherlands	1.08	0.92
Norway	0.27	0.21
Portugal	0.38	0.43
Russia	2.7	2.7
Spain	1.69	1.14
Sweden	0.52	0.42
Switzerland	1.3	0.9
United Kingdom	6.68	3.41
United States	26.46	6.94

Table 20: Standard Prices. Correlations.

	Price f2f	Price f2m	Price m2f	Price m2m
Price f2f	1			
Price f2m	0.965	1		
Price m2f	0.536	0.538	1	
Price m2m	0.529	0.560	0.706	1

Table 21: Summary Statistics of Data

Variable	Mean	S.D.	Minimum	Maximum
Q^{OUT} (10^6 min)	418.5	1,093.8	5.7	16,453.4
Q^{IN} (10^6 min)	492.6	1,194.5	7.7	16,453.4
$Q^{OUT,TDM}$ (10^6 min)	227.1	589.1	5.3	7,172.8
$Q^{IN,TDM}$ (10^6 min)	331.2	636.1	5.9	7,172.82
$Q^{OUT,VoIP}$ (10^6 min)	141.4	548.7	0.2	9.314.4
$Q^{IN,VoiIP}$ (10^6 min)	161.4	606.9	0.3	9,314.4
GDP per capita (USD)	45,168	19,813	1,417	99,635.9
Standard Price f2f (USD)	0.77	1.2	0.03	6.77
Standard Price f2m (USD)	0.88	0.93	0.03	6.76
Standard Price m2f (USD)	1.02	0.71	0.08	4.48
Standard Price m2m (USD)	1.1	0.72	0.07	4.64
Price VoIP Fixed (USD)	0.05	0.02	0.03	0.13
Price VoIP Mobile (USD)	0.2	0.11	0.03	0.31
TotalTrade (10^6 USD)	32,157	42,865.5	515.8	259,319.1
Bilateral Migration	138,121.1	226,462.6	1,134	1,290,190
Fixed Phones per 100 Ppl	42.6	12.9	2.51	63.72
Mobile Phones 100 Ppl	123.21	27.8	62.39	229.24
Internet (%)	77.7	16.2	7.5	95
Fixed Broadband per 100 Ppl	28.4	8.6	0.91	39.89

N=690

Table 22: Estimation Results

	(1) Outgoing Minutes β / SE	(2) Outgoing Minutes β / SE	(3) Outgoing Minutes β / SE	(4) Incoming Minutes β / SE
Outgoing Minutes				0.012
				(0.173)
Incoming Minutes		0.364***	−0.039	
		(0.037)	(0.138)	
Price f2f (d)	−0.238*	−0.297**	0.053	−0.249
	(0.137)	(0.149)	(0.149)	(0.171)
Price m2m (d)	−0.028	−0.023	−0.414***	−0.257*
	(0.094)	(0.098)	(0.145)	(0.134)
Price f2f (f)	0.016	−0.018	−0.033	0.151
	(0.120)	(0.146)	(0.162)	(0.115)
Price m2m (f)	−0.053	−0.143	−0.310**	−0.274*
	(0.095)	(0.097)	(0.144)	(0.147)
Price VoIP Fixed (d)	8.281	4.273	6.658	
	(6.860)	(8.658)	(4.395)	
Price VoIP Mobile (d)	−1.027	−0.486	−0.600	
	(0.802)	(1.160)	(0.666)	
Price VoIP Fixed (f)				5.725
				(4.009)
Price VoIP Mobile (f)				−0.058
				(0.616)
Common Currency	0.116*	0.203***	−0.384***	−0.319*
	(0.067)	(0.073)	(0.130)	(0.165)
Distance	−0.335***	−0.224***	−0.215	−0.393**
	(0.055)	(0.060)	(0.131)	(0.153)
Common Official Language	0.457***	0.285***	0.523**	0.452**
	(0.063)	(0.066)	(0.203)	(0.212)
Common Border	−0.061	−0.020	−0.083	−0.124
	(0.070)	(0.071)	(0.167)	(0.178)
GDP per Capita (d)	0.507	−0.045	−0.110	−0.171
	(0.593)	(0.626)	(0.225)	(0.209)
GDP per Capita (f)	0.203	1.022	−0.284	0.181
	(0.536)	(0.639)	(0.215)	(0.250)
Population (d)	−8.095*	−6.649	0.274**	0.281**
	(4.159)	(4.097)	(0.108)	(0.134)
Population (f)	0.321	−2.106	0.152	0.329**
	(3.731)	(4.096)	(0.107)	(0.136)
Total Trade	0.347***	0.210***	0.355***	0.203
	(0.038)	(0.047)	(0.106)	(0.157)
Bilateral Migration	0.353***	0.217***	0.376***	0.387***
	(0.021)	(0.027)	(0.082)	(0.095)
Fixed Telephones per 100 Ppl (d)	0.859	1.919***	−0.013	−0.088
	(0.528)	(0.733)	(0.265)	(0.214)
Fixed Telephones per 100 Ppl (f)		−1.153	0.116	−0.064
		(0.784)	(0.245)	(0.370)
Mobile Telephones per 100 Ppl (d)	1.944**	3.209***	−0.019	−0.459
	(0.837)	(0.866)	(0.317)	(0.310)
Mobile Telephones per 100 Ppl (f)		−2.760**		−0.248
		(1.210)		(0.348)
Internet (d)	0.022	0.026	−0.623	0.238
	(0.669)	(0.658)	(0.798)	(0.426)
Internet (f)		1.496**	−0.021	−0.561
		(0.690)	(0.393)	(0.520)
Fixed Broadband per 100 Ppl (d)	0.260	−0.778	1.102**	
	(1.002)	(1.027)	(0.494)	
Fixed Broadband per 100 Ppl (f)		−0.793		0.835*
		(1.202)		(0.471)
Observations	690	520	520	540
Adjusted R^2	0.92	0.92		
F Statistics	115	85.62	31.29	25.37
Sargan Test			0.000	0.000
Hansen Test			0.003	0.100

Standard errors in parenthesis.
⋆ Significant at 10 percent
⋆⋆ Significant at 5 percent
⋆ ⋆ ⋆ Significant at 1 percent

APPENDIX B

VARIABLES DESCRIPTION AND SOURCE

DEPENDENT VARIABLES	***DESCRIPTION AND SOURCE***
Wireline	This variable is dichotomous, taking on a value of 1 if the surveyed household subscribed to wireline telephone service at the time of the survey, and is zero otherwise.
	Source: National Health Interview Survey, annual, 2003-2010.
Wireless	This variable is dichotomous, taking on a value of 1 if the surveyed household subscribes to wireless telephone service at the time of the survey, and is zero otherwise.
	Source: National Health Interview Survey, annual, 2003-2010.
NODAL VARIABLES	***DESCRIPTION AND SOURCE***
Retired Household	This variable is dichotomous, taking on a value of 1 if surveyed household includes retired person
	Source: National Health Interview Survey, annual, 2003-2010.
Housewife	This variable is dichotomous, taking on a value of 1 if surveyed household includes member who keeps the house
	Source: National Health Interview Survey, annual, 2003-2010.
Part-Time Employed	This variable is dichotomous, taking on a value of 1 if someone in surveyed household works 20 hours or less
	Source: National Health Interview Survey, annual, 2003-2010.
Limited Youth	This variable is dichotomous, taking on a value of 1 if surveyed household includes member who has health limitations and under age 31
Limited Adult	This variable is dichotomous, taking on a value of 1 if surveyed household includes member who has health limitations and above age 30
	Source: National Health Interview Survey, annual, 2003-2010.
Young Household	This variable is dichotomous, taking on a value of 1 if all members of surveyed household are under age 31
Young-Middle Household	This variable is dichotomous, taking on a value of 1 if all members of surveyed household are between ages 31 and 44
Older-Middle Household	This variable is dichotomous, taking on a value of 1 if all members of surveyed household are between ages 45 and 64
Older Household	This variable is dichotomous, taking on a value of 1 if all members of surveyed household are above age 65
	Source: National Health Interview Survey, annual, 2003-2010.
Wealthy Retired Household	This variable is dichotomous, taking on a value of 1 if all members of surveyed household are above age 65 and have ratio of family income to poverty threshold above 4
	Source: National Health Interview Survey, annual, 2003-2010.
Unrelated Adults	This variable is dichotomous, taking on a value of 1 if surveyed household includes only unrelated adults
	Source: National Health Interview Survey, annual, 2003-2010.
Children	This variable is dichotomous, taking on a value of 1 if surveyed household includes member under age 18
	Source: National Health Interview Survey, annual, 2003-2010.
Student	This variable is dichotomous, taking on a value of 1 if surveyed household includes students
	Source: National Health Interview Survey, annual, 2003-2010.
Own House	This variable is dichotomous, taking on a value of 1 if someone in surveyed household owns the home
	Source: National Health Interview Survey, annual, 2003-2010.
Ratio Working	Ratio of people in the surveyed household who work
	Source: National Health Interview Survey, annual, 2003-2010.
DEMOGRAPHIC VARIABLES	***DESCRIPTION AND SOURCE***

Female Household	This variable is dichotomous, taking on a value of 1 if the surveyed household includes only females, and is zero otherwise.
	Source: National Health Interview Survey, annual, 2003-2010.
Male Household	This variable is dichotomous, taking on a value of 1 if the surveyed household includes only males, and is zero otherwise.
	Source: National Health Interview Survey, annual, 2003-2010.
White	This variable is dichotomous, taking on a value of 1 if the surveyed household consists of white people only, and is zero otherwise.
Black	This variable is dichotomous, taking on a value of 1 if the surveyed household consists of Black/African American people only, and is zero otherwise.
Hispanic	This variable is dichotomous, taking on a value of 1 if the surveyed household consists of Hispanic people only, and is zero otherwise.
Asian	This variable is dichotomous, taking on a value of 1 if the surveyed household consists of Asian people only, and is zero otherwise.
Indian	This variable is dichotomous, taking on a value of 1 if the surveyed household consists of Indian people only, and is zero otherwise.
Chinese	This variable is dichotomous, taking on a value of 1 if the surveyed household consists of Chinese people only, and is zero otherwise.
	Source: National Health Interview Survey, annual, 2003-2010.
Divorced	This variable is dichotomous, taking on a value of 1 if surveyed household includes divorced member
	Source: National Health Interview Survey, annual, 2003-2010.
Population Density	Population density, county level.
	Source: U.S. Census Bureau, annual 2003-2010
PRICE AND INCOME VARIABLES	***DESCRIPTION AND SOURCE***
Wireline Price	*As discribed in the text, see p.11*
	Source: data was supplied by Greg Rosston, Scott Savage and Breadley Wimmer, who collected it for the purposes of the research in Rosston, Savage and Wimmer (2008), adjusted for years 2003-2009
Wireless Price	As discribed in the text, see p. 12
	Source: CTIA's Wireless Industry Report Indices, 2008
CPI for Wireless Telephone Services	Consumer price index for wireless telephone services
	Source: FCC "Reference Book of Rates, Price Indices, and Household Expenditures for Telephone Service", annual
CPI for Wireline Telephone Services	Consumer price index for wireline telephone services
	Source: FCC "Reference Book of Rates, Price Indices, and Household Expenditures for Telephone Service", annual
State and Local Taxes on Wireless Telephony	As discribed in the text, see p. 12
	Source: The Council on State Taxation (COST), years 2001, 2004, 2007, 2010
Income1	This variable is dichotomous, taking on a value of 1 if the surveyed household has family income below the poverty threshold
Income2	This variable is dichotomous, taking on a value of 1 if the surveyed household has a ratio of family income to poverty threshold between 1 and 2
Income3	This variable is dichotomous, taking on a value of 1 if the surveyed household has a ratio of family income to poverty threshold between 2 and 4
Income4	This variable is dichotomous, taking on a value of 1 if the surveyed household a has ratio of family income to poverty threshold is above 4
	Source: National Health Interview Survey, annual, 2003-2010.
QUALITY VARIABLES	***DESCRIPTION AND SOURCE***
Mountainous	Land Surface Form Typography code, ranges from 1 to 21. Higher value indicates more mountainous surface.
	Source: U.S. Department of Agriculture, Area Resource File, http://www.ers.usda.gov/Data/NaturalAmenities/

Water	Percent water area in the county
	Source: U.S. Department of Agriculture, Area Resource File, http://www.ers.usda.gov/Data/NaturalAmenities/
Cellsites	Number of registered cellsites
	Source: CTIA's Wireless Industry Report Indices, annual
Wireline Broadband	Number of residential connections over 200 kbps in at least one direction, by state
	Source: FCC Internet Access Services Report, 2004-2011
EXCLUSION RESTRICTIONS	***DESCRIPTION AND SOURCE***
Telecommunications Wages	Mean annual wage for Telecommunications Equipment and Line Installers and Repairers
	Source: Bureau of Labor Statistics, Department of Labor, 2003-2010
Mobile Penetration	Mobile wireless services penetration rate in a county
	Source: National Health Interview Survey, annual, 2003-2010.

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