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DEMAND FOR MOBILE INTERNET: EVIDENCE FROM A REAL-WORLD PRICING EXPERIMENT*

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Abstract

Mobile phones are increasingly used as a gateway to the Internet. The take-up of mobile phone-enabled Internet services was, however, initially slower than expected, at least in Europe. We estimate non-parametrically the price elasticities of demand for first-generation wireless services using (i) consumer-level panel data from a real world pricing experiment and (ii) the restrictions of a structural model. We decompose the number of wireless connections into the number of needs and the conditional probability of establishing a connection, given a need. According to our estimates needs were plenty, but the conditional usage probability small. Demand for first-generation wireless services was highly elastic and the welfare gains to an (early) adopter moderate. Pricing and taxation of wireless services had a large suppressing effect on demand.

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1 Introduction

The catchy phrase “wireless Internet” became familiar in the late 1990s. Media described how laptops, personal digital assistants (PDAs) and mobile phones would allow access - anywhere, any time - to a new class of wireless services, including those on the Internet. The initial emphasis in the U.S. was more on laptops and PDAs, but wireless internet services using mobile phones (e.g. AT&T’s mMode), on which Europe and Asia initially concentrated, are now (in 2004) being introduced also in the U.S.. Enthusiasm for the new wireless services and wireless Internet resulted in telecom operators sinking over 100 billion euros into European third generation mobile phone licenses 1999-2001 (Klemperer, 2002). The early developments were enabled by new technologies such as the Wireless Access Protocol (WAP) for mobile phones in Europe. The take-up of WAP-enabled wireless services was however not as rapid as expected.[1] Soon after its launch in 1999, some commentators announced WAP a failure.[2] While the current

[1] Take-up was slow also compared to wireless Internet in Japan, where i-mode, a service brand of NTT DoCoMo, took off rapidly after its introduction in February 1999.

[2] For example, the Nielsen Norman Group published a “WAP Usability Report” in December 2000. The report was based on a field study of WAP users in London and had a section titled “WAP Doesn’t Work” in the executive summary. It concluded that “When users were asked whether they were likely to use a WAP phone within one year, a resounding 70% answered no. WAP is not ready for prime time yet, nor do users expect it to be usable any time soon”. See also an analyst report titled “WAP in Europe: Has It Missed the Boat?” (by Lonergan, D. from the Yankee Group, published in 2000). Ph.D. Jacob Nilsen, cited by the Business Week to be “one of the world’s foremost experts in Web usability” and by Stuttgarter Zeitung, Germany “the world’s leading expert on user-friendly design”, called WAP the “Wrong Approach to Portability” in his October 1999 Alertbox -article (October 31, 1999, http://www.useit.com/alertbox/991031.html, accessed 30 May 2004).

view and numbers clearly challenge the most critical accounts,[3] recent developments in Europe raise a number of important questions about the economics of new wireless services: Did something go wrong during the early phases of WAP? Did pricing or taxation suppress demand, or was there no (latent) demand for the first generation of wireless Internet services?

We address these questions by estimating (mostly) nonparametrically the demand for the new wireless services that WAP enabled, using consumer-level data from a real world pricing experiment implemented in Fall 2001, and a structural model of demand. The hype that preceded the introduction suggests that consumers should have benefited a lot. So does recent research, which has found large consumer gains from new goods and services (Trajtenberg 1989, Breshanan and Gordon 1997, Petrin 2002, Brynjolfsson, Hu and Smith 2003, Goolsbee and Petrin 2004) and particularly from telecommunications product/service innovations (e.g., Hausman 1997, 1999). If anybody, the early adopters (lead users) of the new services should have gained. The criticism that followed the launch suggests the opposite.

We find that consumers had demand for the first-generation wireless services, but it remained latent. The annual average satiation (latent) demand was 300 connections per consumer, but the average probability of establishing a connection, given a need, was only 10%. The low connection probability is explained by highly elastic demand. The welfare gains to an (early) adopter were accord-

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[3] Views differ, but many see WAP as a constantly developing technology that now provides a bridge to newer generations of wireless technologies. A concrete example comes from Digital Airways, who introduced in October 2003 a new WAP-compatible version of Wapaka Web, its Java-based WAP simulator for the Web. The motivation was the take-off of WAP. The company states: “We had to respond to a growing demand for a WAP 2.0 version of Wapaka” and “Indeed, WAP is back.” (see http://www.3g.co.uk/PR/Sept2003/5891.htm, accessed 30 May 2004). Recent estimates also speak for the comeback of WAP: According to figures from the Mobile Data Association (the U.K.), the number of WAP page impressions viewed in the UK more than doubled during the nine months prior to May 2003. In Finland, usage has grown similarly. In-Stat/MDR

ingly moderate: our upper-bound estimate for the average welfare gain per consumer is 16 euros per year. We perform a number of counterfactual experiments, one of which demonstrates that abolishing the existing value added tax would have greatly boosted demand. These findings remind us of the high elasticities of Varian (2000) and Goolsbee (2000a) for the early broadband demand and the high tax elasticities of Goolsbee (2000b) and Ellison and Ellison (2003) for the emerging Internet commerce.

Our data that combine individual characteristics and multiple observations per individual over a short time period with a real world pricing experiment enable us to approach the estimation of demand flexibly.[4] We observe the prices charged, and number and average length of connections for a panel of consumers during four non-experimental and three experimental two-week periods. Prior to (periods 1 and 2) and after the experiment (periods 6 and 7), prices were at their normal (equilibrium) levels. During the experiment (periods 3, 4 and 5), both the per-minute price and the fixed connection fee were set to zero. We build a structural econometric model of wireless service usage that allows us to estimate the price elasticity of connection length, and of the number of wireless connections for both the per-minute price and the fixed fee. Armed with these, we can calculate the consumer surplus from the new wireless services. For robustness, we also estimate various reduced form specifications.

Our data come from a Finnish mobile phone operator. Finnish operators have some track record in pioneering new services: The first digital mobile phone (GSM) call in the world was made in 1991 in Finland. Finland is one of the lead-

Group's forecast is that by 2004, the number of WAP users in Western Europe will grow to well over 200 million.

[4] Demand estimates for new services and goods are often wrought with empirical difficulties. Lack of detailed data is a primary reason. Bajari and Benkard (2003) and Berry, Linton and Pakes (2004) spell out some methodological difficulties.

ers in adoption of mobile telephony in general, and of wireless services in particular (see, e.g., Hausman 2002, Rouvinen and Ylä-Anttila 2003). Together with Japan, Finland was among the first countries where customers gained access to more advanced wireless services. One might therefore expect that if anywhere, WAP enabled wireless services should have taken off early in Finland.

The technical solutions currently in use both in Finland and elsewhere are more advanced than the technology used by our operator at the time of the experiment. That technology, an early version of WAP, was a first-generation solution to provide wireless services, such as receiving the latest news, monitoring financial markets, checking out the weather forecast, paying bills, and downloading games and other entertainment. It was in this sense similar to the early versions of NTT DoCoMo's i-mode in Japan. These services are similar in nature - but not necessarily in quality - to those that are now becoming available in the U.S. to the subscribers of AT&T's mMode, for example. In Section 2 we discuss the technology, its relationship to the previous and forthcoming technologies, and the services available.

In Section 3 we present our structural model, derive our estimation equation(s), and discuss our identification strategy. We decompose the number of wireless connections into the number of needs that arise during a two-week period, and the conditional probability of establishing a connection, given a need. The decomposition allows us to study separately the magnitude of latent demand for wireless services and the role of price elasticities. Cross-sectional variation in usage (connection length and number of connections) during the experiment identifies the determinants of saturation connection length and number of wireless connection needs. Together these characterize the latent demand. We identify the price elasticities using these estimated parameters and price-variation induced by the experiment. The price elasticities determine the conditional probability of establishing a connection, given a need. As the data is from an experiment, no instruments are needed.

In Section 4 we detail the data and its characteristics, and present our demand elasticity estimates. We have matched the data on usage and prices with individual characteristics, allowing us to estimate the parameters of demand as functions of those characteristics. We apply mostly non-parametric techniques to estimate these parameters.

We explore the robustness of our econometric findings, compare the key findings to other existing evidence, and discuss some explanations for them in Section 5. We close the paper with a summary in Section 6.

2 The market, the technology and the experiment

2.1 The product

The market we study is the service market enabled by the wireless Internet. The services were accessed with a mobile phone with a "first-generation" micro browser.

The operator whose data we use launched its WAP-based wireless Internet service in late 1999. In 2001, the operator's own service portfolio consisted of some 67 services, ranging from news, sports results and weather services to games, betting results and TV-listings.[5] These services were tailored for a wireless user. The users also had access to external Internet sites. Because of the small screen sizes and limited input capabilities of the early mobile browsers, the range and quality of services that the consumers in our sample were able to access are more limited than what are available today.

Pricing of the early wireless services was simple. A customer paid a fixed monthly fee for her wireless plan. The monthly fee depended on the plan she subscribed to, and no plan offered "free minutes". Nor did the plans involve any leasing of handsets, because Finnish law prohibited the practise.[6] There was no additional monthly fee for using wireless Internet, but an additional data call fee applied to all WAP connections. This fixed connection fee was 0.09 euros per connection. The per-minute online charge was either 0.12 or 0.17 cents, depending on the wireless plan. Customers thus paid for the length of time they were connected.[7]

Additional content charges also applied, but whether there was a charge depended on the service provider.[8] For example, at the time of the price experiment, the cost of downloading a weather radar service with pictures was 0.56 eu-

[5] Kakkori (2001) provides a complete account of the types of services that where available in May 2001 via the operator's own wireless portal: They include search services, ticket order, travel information, weather forecast, certain financial services, health-related services, news, communications, cinema, humour, dating, phone personalization, music, games, radio listings, tips where to eat and drink, TV listings, sports results, horoscope, betting results, and various operator services.

[6] The prices of WAP handsets available in 2001 were, approximately, from 250 EUR (Ericsson R320s) to 435 EUR (Nokia 6210). According to industry estimates, there were about 655000 WAP compatible mobile phones in Finland at the time of the experiment. They accounted for about 16% of the stock of digital mobile phones. The proportion of WAP-enabled phones was growing rapidly, however. It has been estimated that in 2001, nearly half of the new mobile phones were able to utilise WAP.

[7] This is unlike in many current mobile Internet plans, where the customer pays for the total amount of data transmitted and received.

[8] It has been estimated that during 2001, about 60 % of the operator sponsored wireless services had an additional contents charge (Kakkori, 2001).

ros. The fixed cost per game session of “X-Men”, a role-playing game that used graphics relatively lot, was 0.66 euros.[9]

2.2 The technology

WAP is a set of protocols that underlie one strand of the first technologies for the wireless Internet. The devices and services available during the experiment were based on WAP version 1.1. The wireless technologies in use today, including WAP 2.0, are bridging the gap to the third and later generation technologies.

WAP is an outcome of the work of WAP Forum, an industry-wide standard setting organization. The aim of the forum was to bring Internet content and advanced data services to digital cellular phones. The WAP architecture is similar to that of the WWW-browsing architecture, with the exception that WAP requires an intermediate layer (“the WAP gateway”), which determines how the wireless terminal and the Internet-architecture communicate.

Both WAP and the other leading wireless Internet technology of the time, i-mode in Japan, transmitted the data at 9600 bits per second, which is quite slow. The display sizes were also quite small. For example the Nokia 6210 WAP handset, which was probably one of the most often used terminals by the consumers in our data, had a display with 96x60 pixels. Better WAP handsets, such as those supporting colours, were being introduced to the market about the time the experiment was run.

To sum up, the technology that this paper is about is a member of “2G” mobile technologies and has, at least in our view, a crude but illustrative counterpart

[9] See Kakkori (2001, p. 24) for other examples of contents charges. Data on the distribution of the usage between the services with and without additional content charges is not available to us. We know, however, that during the experiment, a large majority (about 95%) of the per-two week charges for WAP-usage were zero (despite the dramatically increased usage). This means that customers accessed services with no additional charges.

in the world of the wireline Internet: Using the early WAP was like having a dial up Internet access. For the user, this means that it may take a while to download data intensive services and/or applications. The wireless technologies currently in use are based on intermediate technologies, often called “2.5G”. For the end-user, they are like a dedicated Internet access (or like using Integrated Services Digital Network, known as ISDN or ISDL, which is an early version of Digital Subscriber Line, DSL) that is often used for data transmission only and that sometimes comes with enhanced quality (speed). Accessing wireless services enabled by the next generation mobile networks (“3G”) is a bit like accessing the Internet using a high-speed connection such as DSL or a cable modem.

2.3 The experiment

The Finnish mobile phone operator whose data we use is one of the major firms in the market. The experiment was conducted as an advertising campaign for the new WAP enabled services, and consisted of lowering the per-minute-price and the fixed connection fee to zero for six weeks in Fall 2001 for all customers of the operator. The operator advertised the campaign in TV, radio, and the major national and local newspapers both before and during the experiment. We believe that all customers with a WAP enabled phone were aware of the campaign taking place. After the campaign, the prices returned to their previous levels.

For our purposes, having zero prices during the experiment is a bonanza, allowing us to estimate the determinants of satiation connection length from data on connection lengths during the experiment periods, and the determinants of the number of needs from the number of connections made during the experiment periods. We then use the price-variation generated by the experiment to estimate determinants of price elasticities.

3 The model and estimation strategy

3.1 The theoretical model

We begin with the analysis of a single wireless service connection: whether or not to make it, and if, at what length. We then expand the model by assuming that there are two types of demand shocks that determine observed behavior. The first shock determines whether a consumer faces a need to consume wireless services; the second, how strong the needs is.

Consider a single consumer contemplating whether or nor to establish a wireless service connection and if so, for how long. We assume that she has a separable utility function for wireless services and other goods:

(1) $U(x,q) = C(x) + W(q) = C(I - K - pq) + W(q)$.

In (1), x is the consumption of the outside good (or, identically, income minus spending on a connection), q the consumption of the wireless service (= connection length in units of time), I is the decision-period compatible income, K is the fixed connection fee of a single wireless service connection, and p is the per-unit-of-time -price of a wireless service connection.[10] Functions C and W (and hence U) are assumed to be increasing and strictly concave in their arguments, and $C'(0) = W'(0) = 0$. If, as is true in our case, $I >> K + pq$,[11] one can approximate (1) by $U(x,q) \approx C(I) - (K + pq)C'(I) + W(q)$. The relevant part of the utility function for our analysis is, after normalization, $V(q) - (K + pq)$. This formula-

[10] Having data on usage of wireless services rather than voice calls means that we do not have to worry about some standard issues in telecommunications demand modelling, such as the utility from receiving calls and, the decision to make a call, or to wait for the other party to call.

[11] During the non-experimental periods in our data, K = 0.09 euros, and p = 0.12 euros/minute (in the most popular subscription plan; see the next section for details). The average wage earner's gross income during a two-week period was 1039.2 euros in Finland in 2001. The net income per day is thus about 100 euros, whereas the cost of an average connection is of the order of 0.4 euros.

tion implies that the consumer has a constant marginal utility of income and that there is no income effect.[12]

Because the consumer establishes a wireless connection only if her consumer surplus from the connection is non-negative, the optimal length of a service connection is

(2) $q(p) = \arg\max\left[V(q) - (K + pq)\right]$

if $CS(p) \equiv \int_p^\infty q(\tau)d\tau \geq K$ and zero otherwise. This decision rule determines (in the deterministic case) whether or not to make a single wireless service connection, and if, at what length.

We introduce two types of demand shocks in our model that determine observed behavior. First, a consumer faces consumption (connection) needs that are derived from a stochastic process. Once a connection need, such as a need to check the latest weather forecast, arrives, the consumer receives a connection-specific demand shock from a known distribution. This shock is a demand shift parameter that determines the strength of the need.

To formalize the idea of the two demand shocks, consider first the demand shock that determines the strength of the need. We follow the long literature on discrete choice by making

Assumption 1: $V(q) \equiv V(q,\alpha)$, where α is an independent and identically distributed random shock with a known probability density function $f(\alpha)$, with support $[0,\infty)$. Further, $V(q,\alpha)$ is increasing in α.

The cumulative density function (c.d.f.) of α is denoted $F(\alpha)$, which we take to be continuous, monotonically increasing, and twice continuously differentiable.

[12] This is a commonly used transformation both in the Industrial Organization literature (see e.g. Tirole, 1988, pp. 143) and telecommunications analysis (Mitchell, 1978).

Coupling Assumption 1 with equation (2) means that *conditional* on a connection need, a consumer will establish a wireless service connection with probability $\pi = [1 - F(\bar{\alpha})]$, where $\bar{\alpha}$ is the unique value of the shock that is implicitly defined by $CS(p;\bar{\alpha}) \equiv \int_p^\infty q(\tau;\bar{\alpha})d\tau \equiv K$. It follows that for a sequence of *y* connection needs, the number of connections established follows a binomial distribution with parameters *y* and π.

To introduce the stochastic process generating the need shocks, we lean on a large telecommunications engineering literature and assume that the needs are draws from a Poisson distribution:[13]

Assumption 2: The number of connection needs, *y*, is distributed Poisson with mean μ.

Assumption 2 means that the expected number of consumption needs for wireless services during the time interval is μ. This parameter captures a key component of the latent demand for the wireless services. Our model, coupled with Assumptions 1 and 2, yields the following result:

RESULT: The number of connections made during a given time interval, Y, is given by a Poisson-stopped Binomial: Y ~ Poisson with $E[Y|X] = \mu\pi$.[14]

Summing up, there are two types of demand shocks that determine observed behavior: First, consumers face connection needs that are derived from a Poisson process. Once a need arrives, the consumers receive a connection-specific draw of α from the distribution $f(\alpha)$, which determines how strong the need is. Given

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[13] See e.g. http://www.jdstelecom.com/telecom.php ("Use to find the number of trunks required for an offered traffic to have a specified probability of blocking. All assume random (Poisson) arrivals and exponential call holding times."), where tools based on our type of modeling of the number and length of calls is promoted (accessed 30 May 2004).

[14] The result follows directly from the properties of the two stochastic processes (see, e.g., Lemma 1.1.4 of Cameron and Trivedi 1998, pp. 8) and Assumptions 1 and 2.

the connection need and armed with knowledge of prices p and K and the value of α, the consumer calculates whether her utility is maximized by establishing a connection of the optimal length, or by not connecting at all. The draws and the decisions rule mean that we observe a sequence of Bernoulli trials, where the outcome takes value one (zero) with probability $\pi = 1 - F(\bar{\alpha})$ $(1 - \pi = F(\bar{\alpha}))$.

3.2 Operationalization of the model

To make the model operational, we have to make further assumptions about the expected number of consumption opportunities for wireless services during the time interval [μ], the density of the demand shift shock [$f(\alpha)$], and the form of demand determining the optimal connection length [$q(p)$].

The number of consumption needs that consumer i faces during time period t, y_{it}, corresponds in our model to the consumer's satiation demand during the period. Satiation demand is typically unobservable. We can however measure it, because during the experiment periods $p = K = 0$, implying that $\bar{\alpha} = 0$ and hence the probability of establishing a connection given a need, $\pi = 1 - F(0) = 1$. The number of connections made during the experiment period therefore reflects complete fulfilment of needs. Thus $y_{it} = Y_{it}$, and by Assumption (2), y_{it} is distributed Poisson with mean μ. We allow for heterogeneity and model the mean satiation demand of consumer i flexibly as a function of demographics. We assume, specifically, that $\mu_i = \exp(g(\mathbf{z}_i; \boldsymbol{\mu}))$, where $g(\mathbf{z}_i, \boldsymbol{\mu})$ is an initially unknown function of the vector of consumer demographics $\mathbf{z}_i$ and the associated vector of parameters $\boldsymbol{\mu}$.

The theory is silent about the distribution of the demand shift parameter α, which assumes a different value for each need that consumer i faces during period t. Following the telecommunications engineering literature, we specify that α has a (stationary) exponential distribution. However, we allow for heterogeneity as follows: $\alpha \sim \exp(\lambda_i)$, with $E[\alpha_{ij}] = 1/\lambda_i$, where j indexes connection needs (j = 0, …, y_{it}) of consumer i during period t . The mean depends on consumer demographics, i.e., $\lambda_i = k(\underset{\sim}{z}_i, \underset{\sim}{\lambda})$, where $k(\underset{\sim}{z}_i, \underset{\sim}{\lambda})$ is an initially unknown function of the vector of consumer demographics $\underset{\sim}{z}_i$ and the associated vector of parameters $\underset{\sim}{\lambda}$.

Absent an established practice, we consider two different demand specifications for $q(p)$. We assume that the demand for the service (and thus the length of the connection) is either a linear ($q_{it,j} = \alpha_{ij} - \gamma_i p_t$) or a log-linear ($q_{it,j} = \alpha_{ij} \exp(-\gamma_i p_t)$) function of the per-minute price p_t. We present all our results using both of these two functional forms. Besides simplicity, the strength of these demand functions is that they allow us to parameterize γ_i as a function of consumer demographics. Consistent with our data, they also allow for a point of satiation.[15] These specifications also make our analysis comparable with many recent analyses of demand for telecommunications services.[16] Finally, using two specifications side-by-side is a robustness check. It turns out in our case that while they generate qualitatively similar results, the linear demand results in somewhat higher consumer surplus.[17]

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[15] We observe a bounded number of connections, and a finite length of connections during the experiment period.

[16] Our analysis differs from the previous studies because we use the two functional forms side-by-side and data on wireless services, not voice calls. In addition, our data is from an experiment, and we use nonparametric estimation methods. For studies using the linear demand function, see for example Miravete (2002) and Miravete and Röller (2003). The log-linear demand is known as "Perl-demand" in the telecommunications literature; see Taylor (2002) for a recent review of this literature.

[17] It has been argued that the linear demand is a conservative assumption when one is interested in calculating the consumer surplus (see Hausman 1997, 1999). The reason for this is that the linear demand curve generates the lowest consumer surplus for a given (estimated) price elasticity.

3.3 Estimation and identification

Together with our econometric assumptions, the theoretical model implies that the number of connections made by consumer *i* during period *t*, Y_{it}, follows a Poisson-stopped Binomial process with mean $E[Y_{it} \mid p_t, K_t, z_i] = \mu_i \pi_{it}$. The conditional mean can be re-written as

$$(3) \qquad E[Y_{it} \mid p_t, K_t, z_i] = \mu_i \left[1 - F(\bar{\alpha}_{it})\right] = \exp(g(z_i, \mu) - \lambda_i \bar{\alpha}(p_t, K_t, z_i, \gamma)),$$

where $\bar{\alpha}(p_t, K_t, z_i, \gamma) = (\gamma' z_i) p_t + \sqrt{2(\gamma' z_i) K_t}$ in the case of linear demand and $\bar{\alpha}(p_t, K_t, z_i, \gamma) = (\gamma' z_i) K_t \exp((\gamma' z_i) p_t)$ in the case of log-linear demand. We impose (3), but not the potentially very restrictive Poisson variance assumption (see, for example, Wooldridge 1997).

In estimating the model, we utilize the unique feature of our data that we have three periods where both prices (p_t and K_t) are set to zero. Although in general we have censoring in the model, i.e., a consumer establishes a connection only if she faces a need *and* if the associated demand shock is large enough, during the experiment periods, there is *no* censoring. The experiment ($p_t = K_t = 0$) implies that whenever there was a need, and whatever the realization of the demand shock, a connection was established. To make full use of this identifying information, we follow a two-stage estimation strategy. In the first stage, we a) use data on the number of connections during the experiment periods to estimate the parameters determining the satiation number of connections (i.e., the expected number of needs of consumer *i*) and b) use the average connection length during the experiment periods to estimate the parameters of the distribution of the demand shift shock. In the second stage, we use the price variation of the experiment to identify the price effects.

The first stage identifies the parameters of latent demand sequentially: First, because y_{it} = Y_{it} for t = 3, 4, 5, variation in the number of connections equals variation in the number of needs. This variation identifies $\mu_i = \exp(g(\underline{z}_i, \underline{\mu}))$. We run Poisson regressions of the form

(4) $E[Y_{it} \mid p_t = 0, K_t = 0, z_i] = \mu_i = \exp(g(\underline{z}_i, \underline{\mu}))$.

for t = 3,4 and 5. We estimate $g(\underline{z}_i, \underline{\mu})$ nonparametrically using a power series estimator and cross-validation. Cross-validation leads to a mean-square error minimizing choice of the number of terms (see Li 1987, and Hausman and Newey 1995). We let $\underline{z}_i$ consist of consumers' age, gender and place of residence, and their powers and interactions.

The other parameter of latent demand is $\lambda_i = k(\underline{z}_i, \underline{\lambda})$, which determines the mean of the demand shift shocks. Variation in connection lengths across consumers during the experiment identifies $\lambda_i = k(\underline{z}_i, \underline{\lambda})$, because every time a consumer faced a consumption need during the experiment, she utilized it with probability one and made a wireless service connection of the length that gave her satiation. In terms of our model, this implies that

(4) $E(q_{it} \mid p_t = 0, K_t = 0, z_i) = 1/\lambda_i = 1/k(\underline{z}_i, \underline{\lambda})$,

for t = 3,4 and 5. To implement the estimation we estimate $k(\underline{z}_i, \underline{\lambda})$ nonparametrically using a power series estimator and cross-validation.

We estimate $k(\underline{z}_i, \underline{\lambda})$ using data on the *average* duration of connections of consumer i during period t, because that is what we observe. As $y_{it} = Y_{it}$ during the experiment periods, $E[q_{it}] = (1/y_{it})\sum_{j=1}^{y_{it}} q_{it,j} = (1/y_{it})\sum_{j=1}^{y_{it}} \alpha_j = E[\alpha_{it}]$ during an experiment period.

In the second stage we estimate the price effects, parameterized by $\gamma' z_i$, and identify them using the variation in the prices induced by the experiment. We allow these price effects to vary with the age, gender and place of residence of the consumer. To estimate γ, we insert $\hat{\lambda}_i$ and $\hat{\mu}_i$ into (3) to obtain

(6) $$E[Y_{it} \,|\, p_t, K_t, z_i] = \hat{\mu}_i \left[1 - \hat{F}(\bar{\alpha}_{it})\right] = \hat{\mu}_i \exp(-\hat{\lambda}_i \bar{\alpha}(p_t, K_t, z_i, \gamma)) .$$

We estimate the parameters in (6) by maximum likelihood, and bootstrap the standard errors because we use the estimated values of λ and μ.

4 Empirics

4.1 Data

In Finland, mobile phone customers buy their phones from private vendors, not from operators. The operator in our case thus does not know how many of its customers had a WAP enabled phone during the observation period. Consequently, we don't know how many of the potential users we have in our data. The data was collected by identifying all customers who during the two middle weeks of the six-week experiment (i.e., during period 4) established at least one wireless Internet connection. Because the expected number of needs during a two-week period varies over customers, this potentially creates some selection. In particular, a customer does not appear in our data if she did not have a need to establish a wireless Internet connection during the second two-week period of the experiment.

Given that the campaign was well advertised, and had been running for two weeks, we think it unlikely that a customer of the operator (who had a WAP enabled phone) was unaware of the campaign. Usage increased considerably during the experiment. Thus we believe there was little selection out of the sample. Similarly, as the time period for the experiment was short, the price experiment was limited to wireless Internet services, there was no phone-number portability in

Finland yet,[18] and the vast majority of mobile phone usage and costs was created from voice calls and SMS messages, we do not believe there was any selection into the sample.[19]

Table 1 displays the descriptive statistics, separately for the non-experiment and experiment periods, as well as the basic consumer demographics. We have a balanced panel with 14882 consumer-period observations (N = 2126 and T = 7). During the non-experiment periods, the average number of wireless connections (WAP_COUNT) per a two-week period is 1.13. The average connection length (CALL_DUR) is 2.66 minutes. During the experiment periods, usage grows dramatically: The average number of needs (=number of connections during the experiment periods) is 11.94 per a two-week period. The average satiation connection length (= length of connection during the experiment period) is 5.54 minutes. There is, however, a lot of variation in these numbers.

The table also shows that we have two kinds of wireless plans in the data: Plan "A" is clearly more popular, as 86% of the consumers subscribe to it. In this plan, the per-minute charge (WAP_PMIN) is 0.12 euros and the fixed connection fee (WAP_K) is 0.09 euros per connection. In the empirics that follow, we use data from this larger plan only; see Section 4.5 for a robustness analysis using data from the less popular plan.

[Insert Table 1 here]

While Table 1 shows that the experiment increases usage dramatically, we cannot infer the price elasticity from these numbers. Usage before and after the experi-

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[18] That is, switching from one operator to another meant that one had to change the number. Number portability was imposed by law in Finland in 2003, resulting in a large increase of switches from one operator to another.

[19] According to our estimates, the probability of having zero needs during the second two-week experiment period is 0.00003 for the average customer.

ment is pretty similar: There was a small decrease in the average number of connections (-0.12 connections), but a small increase in their average length (+0.04 minutes). Contrary to our expectations, there is thus little indication in the data that the experiment would have resulted in increased usage of wireless Internet services (through e.g. learning). We consequently treat the pre- and post-experiment periods identically in what follows.

4.2 Estimation results

We present the "raw" estimation results briefly, because the key insights come from the economic implications of the model. We start from the first stage of our empirical analysis: Table 2 displays the cross-validation results, separately for $\exp(g(z_i,\mu))$ and $k(z_i,\lambda)$.

[Insert Table 2 here]

Table 3 shows the estimated models, with Huber-White standard errors adjusted for clustering within consumers. Wald-tests indicate that the included variables are jointly highly significant.

[Insert Table 3 here]

The results from the second stage are displayed in Table 4. The results are presented both for linear and log-linear demand. Bootstrapping the standard errors is important, for they are about ten times larger than the unadjusted (incorrect) standard errors. Using the bootstrapped standard errors, we see that only the constant, age, gender and the interaction of age and gender are statistically significant at better than the 10% level. This lack of statistical significance may sound disturbing, but is not uncommon to cross-validated specifications. Moreover, we show, in Section 4.5 that our key results are robust to using different specifications.

[Insert Table 4 here]

4.3 Economic implications of the model

Economic implications of the model are summarized in Tables 5 and 6. Table 5 displays price elasticities. We compute the price elasticities for each individual as a function of her demographics and evaluate them at the market price. The elasticities depend somewhat on the demand specification: The average per-minute price (p_t) elasticity of *connection length* is high, ranging from -1.87 (log-linear demand) to -2.28 (linear demand). The range of the elasticities is, however, wide, varying across consumers from -0.20 to -3.62 (linear demand) and from -1.25 to -2.20 (log-linear demand).

We obtain large elasticities also when we compute the price elasticity of the *number* of wireless connections for both the per-minute price (p_t) and the fixed fee (K_t). With linear demand, the per-minute price elasticity of the number of wireless connections is on average -1.59, and ranges from -0.22 to -2.19. The fixed fee elasticity of the number of wireless connections is lower, on average -0.39. With log-linear demand, the elasticities are higher: The per-minute price elasticity of the number of wireless connections is on average -4.47, and ranges from -1.64 to -6.45. The fixed fee elasticity of the number of wireless connections is on average -2.37.

These large elasticities translate into low estimated consumer surpluses. As we will see, the differences in the elasticities between the linear and log-linear demand are not as drastic as they first seem to be. The estimated models turn out to provide a relatively tight range for consumer surplus and yield similar qualitative conclusions.

[Insert Table 5 here]

Table 6 shows the decomposition of the demand for wireless services into the number of needs and the conditional probability of establishing a connection, given a need. The estimated consumer surplus per connection and for time periods of different length are also presented.

[Insert Table 6 here]

The first economic implication is the magnitude of latent demand: The average satiation demand is 11.5 needs per consumer over a two-week period, or about 300 connections a year.[20] There is also a considerable amount of heterogeneity: The number of needs ranges from 6.77 to 19.96 per a two-week period. These numbers suggest that there was latent demand for the new wireless Internet services in Fall 2001.

The second economic implication is that given a need, the conditional probability of opening a connection is small, on average only 10%. In other words, only every tenth need translates into a connection. Again, there is rather considerable heterogeneity, for the standard deviation of the probability is 4%. Note that these numbers are almost identical for the linear and log-linear demand. Because the conditional connection probability is small, the expected number of established connections per consumer is low, about 30 per year.

The results imply that consumers had latent demand for wireless services. Consumption needs arose almost daily, but they were often left unexploited. Figure 1 shows the age profile of latent demand and the conditional probability of opening a connection, given a need. The plot is drawn for the linear demand specification using data for males that live in the Helsinki capital area. It reinforces the earlier finding that consumer heterogeneity is important. It seems that needs decrease with age, but that the probability of actually satisfying the needs using the services increases with age. Thus a 20 year old had almost twice as

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[20] This magnitude of this latent demand is independent from the choice of the functional form for $q(p)$, because for $p_t = 0$, they are identical.

many (latent) connection needs as a 70 year old, but his probability of connection was only half of that of the 70 year old. The pattern for log-linear demand is similar.

[Insert Figure 1 here]

The third economic implication is the estimated consumer surplus. As Table 6 illustrates, the average estimated consumer surplus per connection is 0.54 euros for linear demand, and only 0.039 euros for log-linear demand. The higher price elasticities of the log-linear demand explain this difference. When translated into annual numbers, the per consumer surplus is on average 15.68 euros in the case of linear demand and 1.14 euros in the case of log-linear demand.

The overall level of consumer surplus is more important than the differences in the estimates. Even if we take the larger of the two numbers, the per-consumer welfare from early wireless services was low. It is less than 15% of the gains that satellite TV channel buyers experienced in the U.S. (Goolsbee and Petrin 2004).

The foregoing may sound implausible. What about the real forerunners and lead users? Didn't *any of the users* benefit from the new wireless services? Some indeed did: The range of the estimated annual per-consumer surplus is from 5.36 to 302.19 euros with linear demand. However, even in this linear case, the 90% decile is relatively low, 27.53 euros per year. The range with log-linear demand is from 0.42 to 5.57 euros, suggesting that not even the lead users benefited.

Summing up, these results support two conclusions: First, consumers had demand for wireless services, but it remained latent. Second, the early demand for the wireless Internet was highly elastic. On average, the consumer surplus was moderate at best. Only few lead users benefited, and even for them the consumer surplus in the log-linear case are low.

4.4 Counterfactual experiments

The foregoing suggests that lack of latent demand does not explain why the early take-up was slower than expected. Consumption needs were plenty, but the conditional usage probability was small, suggesting that pricing may have suppressed demand.

To illustrate the importance of pricing for the early usage of the mobile phone enabled wireless services we ask a simple counterfactual question: How much of the latent demand would have been realized, if the per-minute price p_t was set to zero, while the fixed connection fee K_t remained at 0.09 euros. This price configuration is not meant to be optimal. We have chosen it because the marginal cost of producing an extra minute was very low, most likely close to zero.

The demand effect of abolishing the per-minute price, presented in Table 7, is dramatic: The conditional probability of actually using the wireless services given a need is over four times as large as at the actual prices in the case of linear demand. It is almost seven times as large in the case of log-linear demand. The expected number of connections established increases from 30 to 137.5 (linear) or 209.0 (log-linear) per year per consumer. The increase in demand is due to the increased probability that a connection is established when a need to consume wireless services arises. The annual per-consumer surplus also increases, and would have, on average, been at 73.81 euros with linear demand and 52.25 euros with log-linear demand. We conclude that the pricing of the wireless services at the time of the experiment had a strong suppressing effect both on the early demand and perceived consumer benefits from the new services.

[Insert Table 7 here]

In the U.S. the debate in the late 1990s was mostly about the importance of having wide access to the Internet and about how to make people more mobile with their computers. The question of whether to apply taxes on Internet access was a particularly sensitive topic, which led to the passage of the Internet Tax Freedom Act in 1998. The Act restricted how states can tax Internet *access*. It did not, however, place restrictions on sales taxes on Internet purchases per se, only on discriminatory taxes (Goolsbee 2001). In Europe, the trajectory toward the wireless Internet has been different, emphasizing the role of mobile phones. New wireless telecommunications services were not given any "tax protection" in late 1990s. Inspired by the U.S. debate, we examine the effects of taxation on demand of wireless Internet services in Europe to study the potential role of public policy in promoting the diffusion of new wireless technologies.

We ask what would have happened, had the EU placed a moratorium on taxing new wireless services and restricted its member states ability to raise revenue from them. Such a moratorium would not have been entirely implausible, had the EU wanted to speed up the Continent's transition to a more mobile society.

The prices we have used so far are the valued-added tax (22%) inclusive prices. Using our structural model, we can compute what the demand would have been, had the value added tax been zero while keeping the prices net of tax constant. We find that the expected number of connections would have increased, on average, by 41%, up to 41.34 connections per year, with linear demand. For log-linear demand, these numbers are clearly higher, 158% and 75.92. The demand enhancing effect of a tax break would have been significant.

5 Discussion and robustness

To some, our results may seem inconsistent with the conventional wisdom regarding the welfare contribution of the new goods and services. Can it be true that the wireless Internet had close substitutes, and thus a high price elasticity and low consumer surplus, in 2001? We explore potential sources of error, compare our results to other existing evidence, and discuss some explanations.

5.1 Data and specification choices

Are our results an artifact of our estimating sample? We can address this question by re-estimating our model using a smaller sub-sample: We have data from two different wireless plans (plans “A” and “B”). So far, we have only used the data on the consumers who subscribed to the more popular plan (“A”). In our data, 306 consumers subscribed to the less popular plan (“B”). For our purposes, this plan is otherwise similar to the more popular plan, but for the per-minute price: The per-minute price is 0.17 euros, which is 42% higher than the per-minute price in the more popular plan.

We repeat our empirical analysis stage-by-stage using the data on the “B” subscribers. In the first stage, the cross-validation results suggest that the simplest model (Model 1 in Table 2) now suffices. The second stage estimates imply elasticities that are high. The average per-minute price (p_t) elasticity of connection length ranges from -2.04 (log-linear demand) to -2.91 (linear demand). We also obtain large price elasticities of the number of wireless connections for the per-minute price and the fixed fee. For example, the per-minute price elasticity of the number of wireless connections is on average -1.78, and ranges from -0.82 to -3.20 for the linear demand. The magnitude of latent demand is not negligible: The average number of needs per consumer is 14.36 per a two-week period. However the conditional probability of opening a connection is (again) small, on average about 9%. When translated into annual numbers, the per consumer surplus is on average 18.33 euros in the case of linear demand and 1.54 euros in the case of log-linear demand. These results are in line with the results we obtained using the data on the more popular plan.

Are the findings of high latent demand, low usage probability, and small consumer surplus due to the econometric specification we have chosen? A simple way to check the robustness of our results is to consider simpler econometric models that are consistent with our theoretical setup. We obtain a simple model if we impose that there is no consumer heterogeneity, i.e., that $\mu_i = \mu$, $\lambda_i = \lambda$ and $\gamma_i = \gamma$ for all *i*. The results echo our previous findings, except of course for the role of consumer heterogeneity, which we now assume away. In the linear demand case, for example, latent demand is 11.53 connections per a two-week period, and the conditional connection probability is 9.72%. The annual average consumer surplus is 15.53 euros per consumer. We have repeated our analysis also for a number of other combinations of the explanatory variables, but have found no differences in the results. We conclude that our results are robust to using alternative econometric specifications.

A deeper criticism challenges our entire theoretical model. To provide an alternative estimate, we generate a standard reduced form estimate of consumer surplus in spirit of Hausman (1981, also 1997, 1999) and Brynjolfsson, Hu and Smith (2003). Hausman shows that a good measure of the total effect of the introduction of new wireless services on consumer welfare can be based on compensating variation (CV). In our case, the relevant CV is the difference in the consumer's expenditure function between the expenditure at the market prices and at the service's virtual price, which is the price that sets the service's demand to zero. These expenditures are measured at the level of the utility received once the new service is on the market. Hausman (1999) shows that a practical way to compute the welfare gain is to use the approximation $CV \approx -0.5pY\varepsilon^{-1}$, where Y is the quantity consumed, p is the price, and ε is the own-price elasticity.

In our case, direct application of the above approach is complicated for three reasons. First, what is Y? Is it the number or total length of the wireless connections? Our theoretical model would give clear guidance for the choice, but here we might want to depart from it. Second, even if the choice of Y was unambiguous, what is p? Is it the per-minute price or the fixed connection fee, or some combination of these two components of the two-part tariff? Third, what functional form should we use to estimate ε? The standard log-log linear form (see Hausmann 1981, Brynjolfsson, Hu and Smith 2003) is an option, but it cannot in our case be linearized conveniently by taking logarithms, because Y is frequently zero. The price, however defined, is zero during the experiment periods, too.

To obtain an estimate that is comparable to our basic estimates, we assume that Y is the number of connections made. We consider a simple choice for *p:* We compute the average of connection lengths over all consumer-period observations for which the length is positive, using data from the non-experiment periods only. We then take as the imputed price per connection the sum of the fixed connection fee plus the average outlay per connections, defined as the product of the per-minute charge and the average connection length. This imputed total price is 0.42 euros per connection. Finally, to estimate the elasticity, we regress the number of connections on the imputed total price using a standard Poisson regression. Table 8 summarizes the results.

[Insert Table 8 here]

The numbers show that the early demand for wireless Internet was extremely elastic and that on average, the realized benefits were negligible at best. We further estimate the elasticities and consumer surpluses in a couple of alternative ways.

First, we replicate the results of Table 8 by estimating a standard linear model with ordinary least squares. The coefficient of the price variable is -115.70, which results in even lower consumer surplus. Second, we use a different imputed per connection price: If we simply take the "total" price to be the fixed connection fee, which is 0.09 euros, plus the per-minute price, which in the more popular plan is 0.12 euros, we obtain an elasticity estimate that is clearly lower, about one fifth of that presented in Table 8. The estimated consumer surpluses remain, however, negligible at 1.31 euros per consumer per annum. Finally, we allow for consumer heterogeneity: Estimating a fixed-effects Poisson (Hausman, Hall, and Griliches, 1984) reinforces the finding of highly elastic demand: At the imputed total price of 0.42 euros per connection, the own-price elasticity is -10.83. Using the demographic variables as an alternative way to control for the heterogeneity produces- very similar results. Taken together, these alternative welfare calculations echo our earlier estimates.

5.2 Comparability with existing evidence

Many studies suggest that the demand for new goods and services is relatively inelastic, particularly in the mobile telecommunications sector (Hausman 1997, 2002). In this light our results seem puzzling. However, there is an emerging literature on the demand for Internet and Internet access that comes close to the analysis of this paper and provides some supporting evidence. Goolsbee (2000a) finds that the demand elasticity for broadband Internet access ranged from -2.2 to -3.7 in the U.S around 1999. Varian (2000) portrays a similar picture. Using data from the Berkeley INDEX experiments, he finds that the own-price elasticities for bandwidth were between -2 and -3. Finally, Ellison and Ellison (2001) study the effects of price search on the Internet on demand elasticity, and document Internet price elasticities that are very high, sometimes of magnitude -50. None of these studies is directly comparable to ours, but they put our findings into perspective.

5.3 Potential explanations

Our results raise the question of why latent demand was not realized, i.e., why the conditional usage probability was low. The most likely explanation is that while the wireless Internet, as we now know it, has the potential to make a difference in the way people live and work, the early wireless services had close substitutes especially after an adjustment for quality. Early WAP compatible mobile phones had a relatively small screen and keypad, which probably meant that they were somewhat difficult to use. They did not support (many) colors either. This reduced the quality of the services that use graphics, such as games and maps. The early wireless Internet technologies were also quite slow.

While people in general value mobility, we conjecture that the early services did not constitute a fundamentally “new good” that would have radically reduced an individual’s cost of being mobile. One reason for this is that the early wireless services essentially repackaged a set of existing digital services that were relatively easily available - even to a mobile person - through other channels of distribution. In Finland and elsewhere in Western Europe, there were alternative means of getting many of the Internet services that were offered as a wireless service: The availability of the basic wireline Internet access was relatively widespread by 2001, and we conjecture that the (quality-adjusted) cost of access was competitive relative to the wireless services. Broadband access to the Internet was gaining increasing prominence, too (see e.g. OECD 2001). Short message services, SMS, provided a substitute for the non-voice person-to-person communication that WAP enabled. More generally, the amount of truly new “content” *not* available except by using the early wireless services was scant. Finally, the new content that was available for a mobile consumer only through WAP, such as some types of games and maps, suffered disproportionately from the early quality problems.

The foregoing sets our findings into a perspective: the early users of WAP enabled wireless technologies had demand for the services, but because their quality-adjusted prices were high relative to the substitutes on the market, demand often remained latent. This view is consistent with the finding that the early demand was highly elastic and that the realized benefits were moderate at best.

A comparison of the success of the early WAP with the early diffusion of i-mode, a service brand of NTT DoCoMo which took off quite rapidly after its introduction in February 1999 in Japan, provides a reality check to this interpretation.[21] First, it has been documented that while i-mode was technically not dramatically better than WAP in any single dimension, its overall usability was somewhat better. It was, for example, a bit faster, and supported colors. This suggests that holding other things constant, the quality adjusted price of i-mode enabled services was more competitive than that of WAP. Second, around 1999-2000, the early i-mode services seem to have been a degree or two more novel in Japan than WAP was in Europe. When i-mode as introduced, the take up of wireline Internet was relatively modest in Japan compared to Western Europe. A number of the services made available by i-mode, such as messages across operators' networks or picture downloads, were *not* widely available in Japan before. Especially entertainment related services, such as "What's new" -information services and music sites, became popular early on (Marketing Interactive Network, 2000). The amount of truly new wireless content *not* available except by using i-mode was thus not as scant as was in Europe, suggesting less repackaging.

[21] Most of the descriptive details in this paragraph are from Kakkori (2001).

Finally, the level of prices differed. While reliable comparisons are difficult due to differences in the pricing principles (i-mode's package based vs. the two-part metered tariff in our case) and especially due to lack of comparable data, simple price comparisons suggest that the prices of the early wireless services were, at least in Finland, higher than the prices of comparable services in Japan. Consider the following back-of-the-envelope calculation: In Spring 2001, the monthly fee for the i-mode service was 2.73 euros. In addition, one packet, i.e., 128 bytes, cost 0.0027 euros. If a representative wireless connection in our data had involved a transfer of 2 kilobytes, the cost of making the connection would have been around 0.045 cents. Holding the quality of the service constant and treating the cost as the fixed cost of establishing a connection, the consumer surplus per month would have been from 5.2 (log-linear) to 6.7 (linear) euros in our data. It is almost thrice as large as the monthly fixed fee that i-mode subscribers paid, translating into annual *net* consumer surplus of 29-47 euros per consumer. These consumer surpluses are 80-194% higher than the larger of the average WAP user's surpluses (16 euros) we presented in Table 6. If one took into account differences in service quality (see above) and in purchasing power, the difference would be larger.

This comparison of the success of the early WAP with the early diffusion of i-mode seems consistent with the interpretation that the prices of wireless Internet services may have had a surprisingly large suppressing effect on the early demand.

6 Conclusions

Mobile phones are increasingly used as a gateway to the Internet. In Europe, the early take-up of the new class of wireless services enabled by mobile phones was initially slower than expected. We studied why.

We estimated the price elasticities of demand for first-generation wireless services using (i) consumer-level panel data from a real world pricing experiment that set the per-minute price and the fixed connection fee to zero for six weeks for all customers of the operator whose data we have access to and (ii) the restrictions of a structural model. The model decomposes the number of wireless connections into the number of needs to consume wireless services and the conditional probability of establishing a connection, given a need. We use data on the number of connections during the experiment to estimate non-parametrically the parameters determining the number of needs. We then use data on connection lengths during the experiment to estimate non-parametrically the parameters determining saturation length of wireless connections. These determine latent demand. With these parameters in hand, we identify the determinants of price elasticities using price-variation induced by the experiment. The price elasticities allow us to calculate the conditional probability of establishing a connection, given a need. No instruments are needed.

Our estimates suggest that needs were plenty, and thus lack of latent demand cannot explain the sluggish early adoption. The conditional usage probability was small. We found wide variation in the number of needs, and the usage probability. The results show that demand for the first-generation wireless services was highly elastic. The welfare gains to an (early) adopter of these services were moderate, 1-16 euros a year on average. These findings are consistent with the early adoption experiences and critical accounts that were aired at the time our experiment was run. Counterfactual experiments establish that pricing and taxation of the services had a strong suppressing effect on the early demand.

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Table 1. Descriptive statistics

Non-experiment periods 1-2 and 6-7	Obs: N*4	Mean	Std. Dev.	Min	Max
Connection duration (CALL_DUR)					
- Fraction > 0	8504	0.239	0.427	0	1
- Connection length, conditional on > 0	2034	2.661	2.992	0.047	77
Number of connections (WAP_COUNT)	8504	1.131	4.568	0	118
Price per minute (WAP_PMIN, euro / min)					
- Wireless plan "A"	7280	0.120	0	0.12	0.12
- Wireless plan "B"	1224	0.170	0	0.17	0.17
Fixed per-connection fee (WAP_K, euros)	8504	0.090	0	0.09	0.09

Experiment-periods 3-5	Obs: N*3	Mean	Std. Dev.	Min	Max
Connection duration (CALL_DUR)					
- Fraction > 0	6378	0.797	0.402	0	1
- Connection length, conditional on > 0	5086	5.542	4.729	0.067	64
Number of connections (WAP_COUNT)	6378	11.942	22.213	0	325
Price per minute (WAP_PMIN, euro / min)					
- Wireless plan "A"	5460	0	0	0	0
- Wireless plan "B"	918	0	0	0	0
Fixed per-connection fee (WAP_K, euros)	6378	0	0	0	0

Consumer characteristics	Obs: N	Mean	Std. Dev.	Min	Max
Age (AGE, in years)	2126	36.45	12.41	18	86
Gender (GENDER, Male = 1)	2126	0.72	0.45	0	1
Location (CITY, Helsinki area = 1)	2126	0.23	0.42	0	1
Subscription plan (SUBTYPE, "A" = 1)	2126	0.86	0.31	0	1

Table 2. Cross-validation results

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
CONSTANT	X	X	X	X	X	X
AGE	X	X	X	X	X	X
GENDER	X	X	X	X	X	X
CITY	X	X	X	X	X	X
GENDER*AGE		X	X	X	X	X
CITY*AGE		X	X	X	X	X
GENDER*CITY		X	X	X	X	X
AGE^2			X	X	X	X
$GENDER*AGE^2$				X	X	X
$CITY*AGE^2$				X	X	X
AGE^3					X	X
$GENDER*AGE^3$						X
$CITY*AGE^3$						X
Cross-validation						
of exp(g(.))	2588.502	<u>2585.69</u>	2588.231	2590.941	2591.215	2601.392
of k(.)	110.1632	110.1178	110.0678	110.0267	<u>109.8905</u>	110.023

Table 3. Estimation results from the first phase

Dependent variable	WAP_COUNT		CALL_DUR	
	Coefficient	Std. error*	Coefficient	Std. error*
AGE	0.010	0.006	-0.069	0.036
GENDER	0.112	0.291	-0.051	0.325
CITY	0.404	0.268	-0.609	0.313
GENDER*AGE	-3.8E-03	6.5E-03	-7.3E-03	1.6E-02
CITY*AGE	-0.017	0.006	0.025	0.017
GENDER*CITY	0.046	0.161	-0.028	0.077
AGE^2	-	-	1.5E-03	7.9E-04
$GENDER*AGE^2$	-	-	1.7E-04	2.0E-04
$CITY*AGE^2$	-	-	-3.1E-04	2.2E-04
AGE^3	-	-	-1.1E-05	5.4E-06
CONSTANT	2.133	0.277	2.814	0.522
Obs.	5460		4350	
Wald (joint significance)	36.91		67.61	
d.f.	6		10	
p-value	0.000		0.000	
Log-likelihood	-66434.57		-5555.11	

*Huber-White heteroscedasticity robust covariance matrix, adjusted for clustering across consumers

Table 4. Estimation results from the second phase

Parametrization of gamma						
Model	Linear demand			Log-linear demand		
	Coefficient	Std. error*	Std. error**	Coefficient	Std. error*	Std. error**
AGE	-1.083	0.035	0.381	-0.096	0.004	0.037
GENDER	-41.497	2.073	17.329	-3.796	0.197	1.487
CITY	-5.828	2.398	19.944	-0.912	0.220	1.759
GENDER*AGE	0.965	0.043	0.412	0.090	0.005	0.039
CITY*AGE	-0.263	0.043	0.379	-0.032	0.005	0.040
GENDER*CITY	-8.206	1.354	11.469	-0.296	0.146	1.077
CONSTANT	102.003	1.825	16.204	20.068	0.178	1.409
Obs.	12740			12740		
Log-likelihood	-85963.512			-86007.262		

*unadjusted standard error
**bootstrap standard error

Table 5. Elasticity estimates

Linear demand	Mean	Std. Dev.	Min	Max
The price elasticity of:				
- wireless connection length				
w.r.t. per-minute price	2.280	0.534	0.204	3.616
w.r.t. fixed connection fee	-	-	-	-
- # of wireless connections				
w.r.t. per-minute price	1.590	0.285	0.222	2.190
w.r.t. fixed connection fee	0.390	0.032	0.182	0.457

Log-linear demand	Mean	Std. Dev.	Min	Max
The price elasticity of:				
- wireless connection length				
w.r.t. per-minute price	1.869	0.145	1.254	2.201
w.r.t. fixed connection fee	-	-	-	-
- # of wireless connections				
w.r.t. per-minute price	4.469	0.922	1.643	6.445
w.r.t. fixed connection fee	2.367	0.339	1.304	2.982

Table 6. Economic implications

Linear demand	Mean	Std. Dev.	Min	Max
Expected number of needs (μ)				
- per two-week period	11.539	1.485	6.770	19.959
- per year	300.015	38.614	176.019	518.925
Prob(connect / need) (π)	0.100	0.042	0.045	0.557
Expected number of connections established				
- per two-week period	1.128	0.415	0.500	6.267
- per year	29.325	10.784	12.996	162.951
Estimated consumer surplus				
Consumer surplus, per connection (euros)	0.535	0.082	0.412	1.855
Consumer surplus over time				
- per two-week period (euros)	0.631	0.374	0.207	8.059
- per year (euros)	16.415	9.729	5.372	209.531

Log-linear demand	Mean	Std. Dev.	Min	Max
Expected number of needs (μ)				
- per two-week period	11.539	1.485	6.770	19.959
- per year	300.015	38.614	176.019	518.925
Prob(connect / need) (π)	0.100	0.039	0.051	0.271
Expected number of connections established				
- per two-week period	1.128	0.371	0.533	3.104
- per year	29.321	9.650	13.868	80.699
Estimated consumer surplus				
Consumer surplus, per connection (euros)	0.039	0.007	0.030	0.069
Consumer surplus over time				
- per two-week period (euros)	0.046	0.024	0.016	0.162
- per year (euros)	1.199	0.622	0.420	4.202

Table 7. Counterfactual: Setting the per-minute price to zero

Linear demand	Mean	Std. Dev.	Min	Max
Prob(connect / need) (π)	0.459	0.030	0.401	0.695
Expected number of connections established				
- per two-week period	5.289	0.740	3.543	10.644
- per year	137.505	19.227	92.124	276.753
Estimated consumer surplus				
Consumer surplus, per connection (euros)	0.535	0.082	0.412	1.855
Consumer surplus over time				
- per two-week period (euros)	2.839	0.664	1.799	10.066
- per year (euros)	73.809	17.261	46.766	261.714

Log-linear demand	Mean	Std. Dev.	Min	Max
Prob(connect / need) (π)	0.697	0.015	0.589	0.733
Expected number of connections established				
- per two-week period	8.039	1.068	4.596	12.298
- per year	209.006	27.764	119.486	319.742
Estimated consumer surplus				
Consumer surplus, per connection (euros)	0.250	0.014	0.170	0.289
Consumer surplus over time				
- per two-week period (euros)	2.010	0.322	1.068	3.156
- per year (euros)	52.248	8.371	27.759	82.064

Table 8. Alternative elasticity and consumer surplus calculation

	Own-price elasticity	Annual per-consumer surplus (euro)
Poisson regression	-10.84	0.56

Figure 1. Consumption needs and the conditional connection probability