Demand Estimation for Subscription Models

Identifying Willingness to Pay without Price Variation

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Subscription business

- Subscription market is fast growing and potentially huge
  - Growth rate $> 100\%$ each year in the past 5 years
  - Multibillion revenue per year
  - Across a wide range of product categories (digital + physical)
  - **Pay upfront and consume over time**

Frontier Airlines Now Has an Unlimited Pass for Summer — Here's How to Score One

"For people with flexible schedules, this is a terrific opportunity to have a truly epic summer and then some, soaking up rays on the beach, exploring national parks and visiting new cities."

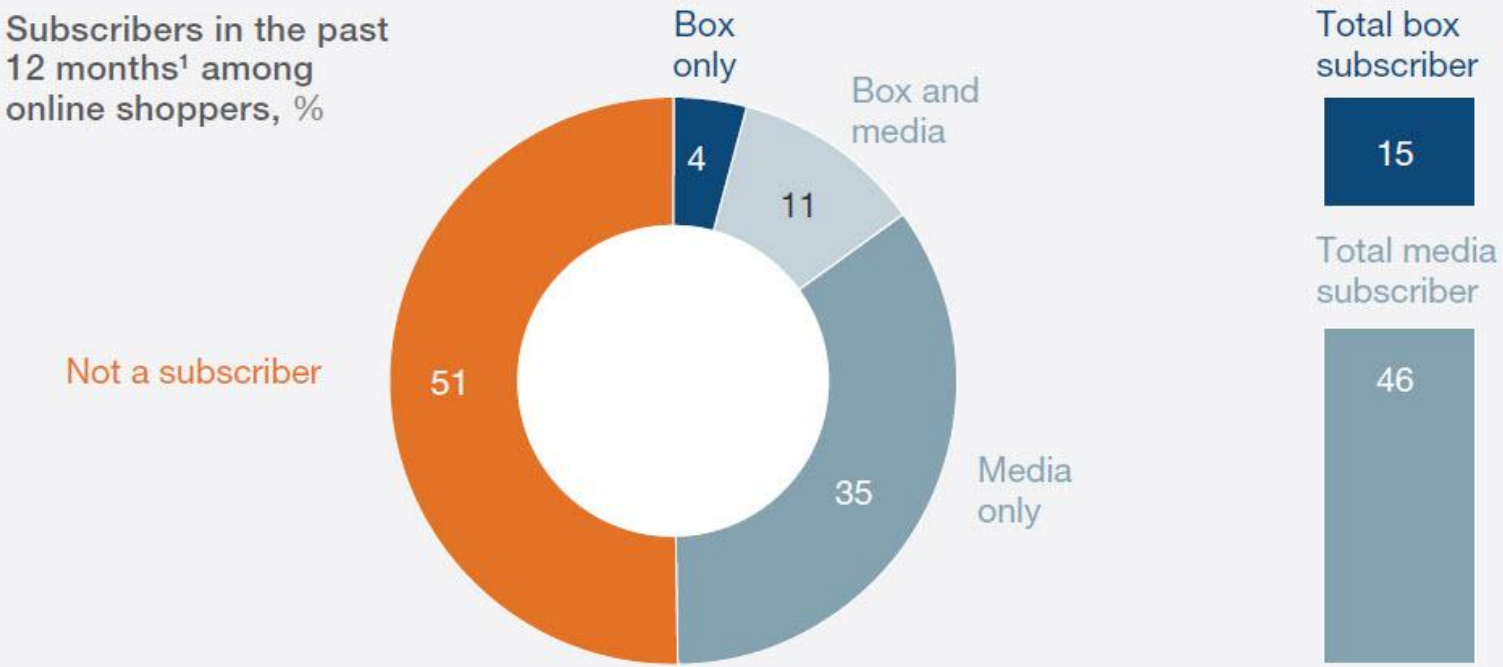
By **Alison Fox** | Updated on February 1, 2023

Pay in advance with (un)limited usage

Industry	Product or Service	Price ($)	Period	Total subscribers
Media & Entertainment	Netflix	9.99	Monthly	23 million (US)
	Spotify	9.99	Monthly	70 million (World)
	New York Times	3.75	Weekly	4 million (US)
	MoviePass	19.95	Monthly	2 million
	Kindle Unlimited	9.99	Monthly	–
	Apple News	9.99	Monthly	36 million
Software-as-a-Service	Microsoft Office 365	9.99	Monthly	120 million
	Adobe Creative Cloud (One App)	20.99	Monthly	15 million
	Dropbox Premium	9.99	Monthly	>11 million
Membership Clubs	Costco (Basic)*	60	Annual	94 million
	Amazon Prime	119	Annual	90 million
	24 hour fitness (Gym)	40	Monthly	4 million
eCommerce	Harry's	35	Monthly	–
	Birchbox	15	Monthly	2 million
	Rent the Runway	159	Monthly	6 million
Transportation	Public Transit Pass (MTA)	121	30-days	–
	Uber Ride Pass*	14.99	Monthly	–
	Jetblue "All You can Jet" Pass	699	Monthly	–

Subscription Services

Subscriptions are an increasingly common way to buy products and services online.

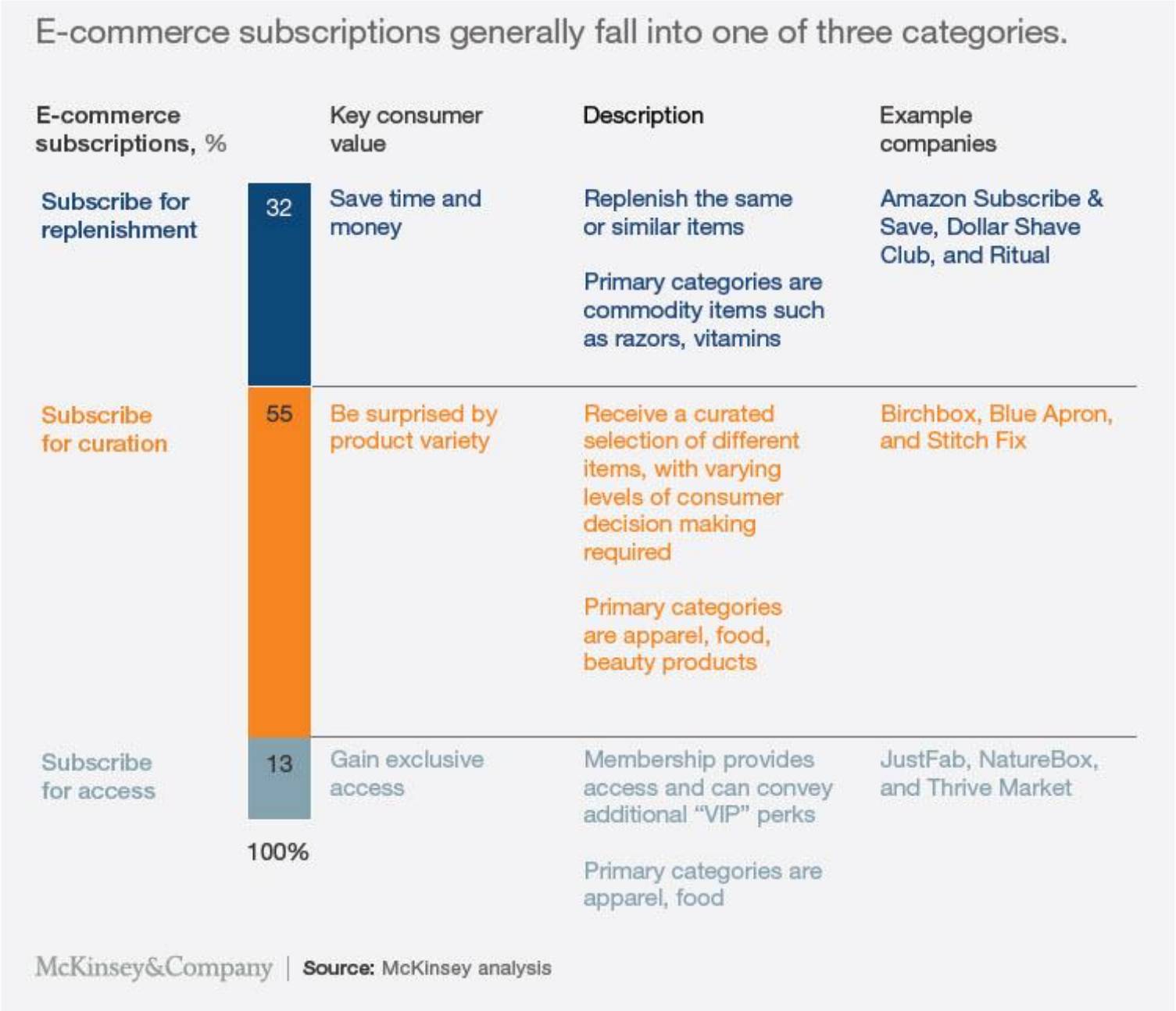


Note: Figures may not sum to 100%, because of rounding.

[1]Which of the following have you purchased or subscribed to in the past 12 months? % of those selecting online subscription-box service that delivers products regularly (eg, Blue Apron, Dollar Shave Club, Ipsy, Stitch Fix), subscription-based media (eg, ClassPass, Hulu, Netflix, Spotify), both, or neither.

McKinsey&Company | **Source:** McKinsey analysis

Subscription Services



Subscription business

- Design product + pricing in subscription markets:
  - Which plans to offer?
  - What feature or value dimensions to offer in each plan?
  - How to price the plans?
- Everything relies on knowing the distribution of **willingness to pay (WTP)** for subscription service.
  - Demand curve
  - Elasticities of the WTP to product changes

Related Research on obtaining WTP

- WTP has been a topic of interest in marketing and economics
- Conjoint typically helps in figuring out valuation or part-worths for attributes (Green and Rao, 1971)
- Revealed preference stream uses transaction data for demand estimation, with individual data (Guadagni and Little 1983) or aggregate data (Berry 1994, BLP 1995)
- Comprehensive Survey: Breidert (2007)
- All these cases have price variation!

All these cases have price variation!

Contribution

- Main contribution: a novel method to identify & estimate semiparametrically the distribution of WTP given customer characteristics and product features **when only usage variation is present**, and exogenous shifters for leisure.
- We also obtain the conditional WTP distribution (so, we can get WTP based on observables like gender / age / student etc.)
- No existing research that demonstrates how to obtain the WTP distribution in the **absence of price variation**.
  - Nevo, Turner and Williams (ECTA, 2016) leverages an "overage charge"

Research questions

- Focus: Obtain WTP estimates for a subscription service

1. In absence of price variation, under what conditions on usage is it possible to identify distribution of WTP?
2. What demand responses and profits to counterfactual product and pricing choices by the firm can be determined?
3. Is price variation the same as usage variation or is there *additional* value?

Big usage data of YBOX, a music streaming service

- YBOX is a music streaming service targeting Southeast Asia.
- 1 million users data (Jan 2015–Feb 2017):
  - subscription history
  - daily # of seconds listening music with the service
  - basic demographics (age and gender)
- No price variation for monthly music streaming service over time
- Average daily listening hours range from 45 mins to $>$ 6 hours
- Average monthly listening hours range from less than 1 hour to more than 150 hours.

With Price Variation

Cross section data with price variation.

Notation

- i indicates a consumer
- Subscription decision: $S_i = 1$ (sub) and $= 0$ (not).
- WTP: W_i
- Price: P_i

- Decision rule:

$$\underbrace{W_i - P_i}_{\substack{\text{money-metric} \\ \text{utility of service}}} \quad \text{vs} \quad \underbrace{\mu = 0}_{\substack{\text{money-metric utility} \\ \text{of outside option}}} \quad \Rightarrow$$

$$S_i = \begin{cases} 1, & W_i > P_i \\ 0, & W_i \leq P_i. \end{cases}$$

or $S_i = \mathbb{I}(W_i > P_i)$.

- When $W_i \perp\!\!\!\perp P_i$, for any w in the support of P_i

$$\underbrace{\Pr(W_i > w)}_{\substack{\text{Parameter: prob WTP} \\ \text{}}} = \underbrace{\Pr(S_i = 1 \mid P_i = w)}_{\substack{\text{Data: Mkt shr in the pop} \\ \text{}}}.$$

Model Overview and Elements

Model is based on microfoundations of usage based on leisure, and aggregated over time

- **(High frequency): Consumer has a daily leisure budget, allocated between focal good and everything else**
- Exogenous shifters impact leisure budget
- Form expectations over the daily leisure process, conditional on observables
  - Rational expectations (or perfect foresight)
- (Low frequency): Consumer makes purchase (subscription) decisions every T periods at constant price P

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Microfoundations of Usage

Consider the consumer allocating leisure time:

- **consumer leisure time spent in focal activity, e.g. listening to streaming music q_{it},**
- Other leisure activities (e.g. playing outdoors) q_{0it}.
- Specify a money-metric utility function:

$$\max u_{it}(q_{it}, q_{0it}) \text{ subject to } q_{it} + q_{0it} = \ell_{it}$$

$$u_{it}(q_{it}, q_{0it}) = D_{it} u^{(1)}(q_{it}, q_{0it}; \theta_{im(t)}) + (1 - D_{it}) u^{(0)}(q_{0it}; \theta_{im(t)})$$

- $D_{it} \in \{0, 1\}$ is an indicator for whether the focal activity is present or absent $\implies$ rationalizes zero usage in many periods

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Microfoundations of Usage

We need to characterize usage at the daily level and relate to the monthly level WTP

- **Daily leisure is modeled as depending on exogenous factors Z_{it}:**

$$\ell_{it} = \mu_i + \gamma' Z_{it} + \varepsilon_{it},$$

- μ_i is heterogeneous across individuals
- Z_{it} includes example variables like weekend or holiday dummy variables or weather
- Leisure shocks ε_{it} can be serially correlated (ignore for now)
- Monthly expected leisure $\boxed{L_{im} \equiv \sum_{t:m(t)=m} (\mu_i + \gamma' Z_{it})}$

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Characterization of Value for Subscription

Connecting daily usage of focal service to monthly indirect utility:

Theorem (Usage to Indirect Utility)

For any utility function homogeneous of degree 1, the difference between the expected monthly indirect utilities with and without a subscription, W_{im}, satisfies

$$W_{im} = \alpha_{im} L_{im} \qquad \textbf{or} \qquad \ln W_{im} = \ln \alpha_{im} + \ln L_{im},$$

- The daily usage of the subscription satisfies

$$Q_{it} = D_{it} r_{im(t)} \ell_{it},$$

- What class of utility functions are included?
  - Cobb-Douglas, CES, perfect substitutes, perfect complements, Leontief

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Subscription Decisions

We know that WTP is: $W_{im} = \alpha_{im} L_{im}$

- **account of consumer heterogeneity, both observed X_{im} and unobserved U_{im}. Consider a linear projection of $\ln \alpha_{im}$ onto X_{im} as:**

$$\ln \alpha_{im} = \beta_0 + \beta_1' X_{1im} + U_{im},$$

where $\beta' = (\beta_0, \beta_1')$ and $X_{im}' = (1, X_{1im}')$.

- Subscription choice $S_{im} = \mathbb{I}(\ln W_{im} > \ln P)$ becomes

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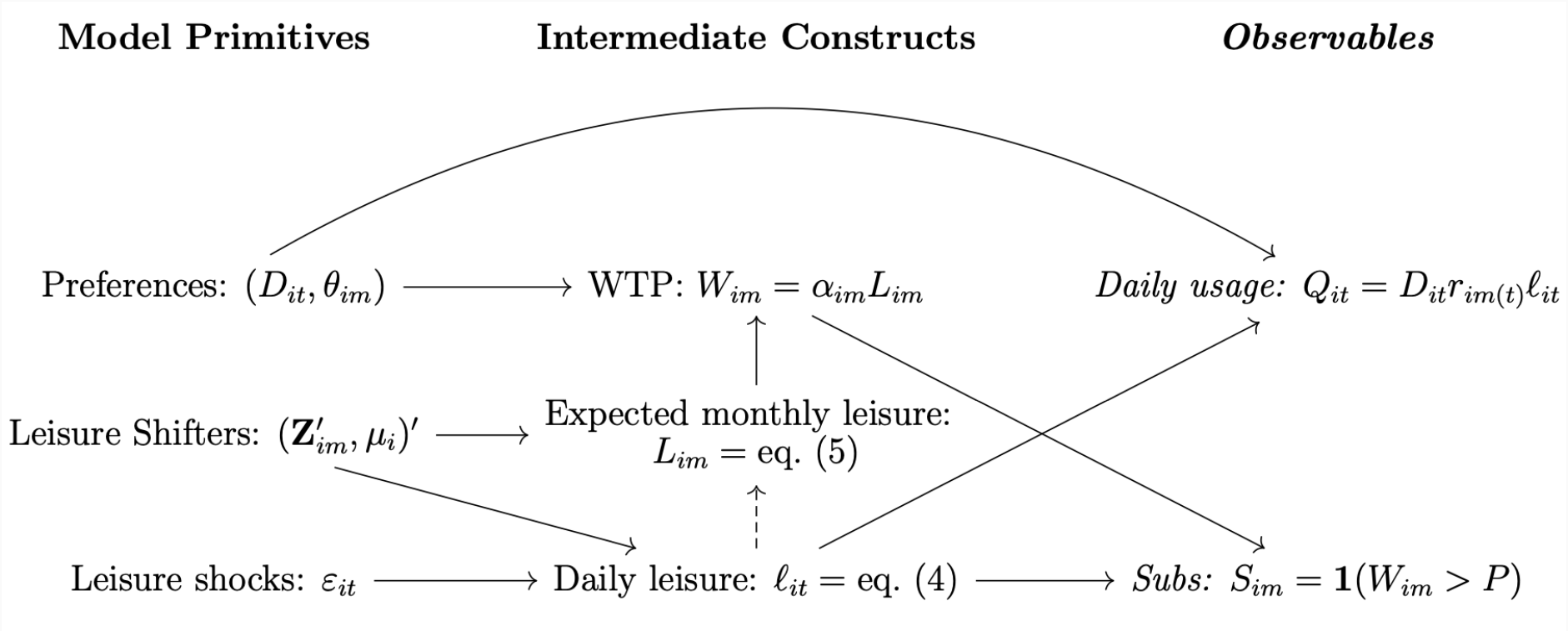
What exogenous variations are required for identification?

Assumption (Exogenous Variation in Leisure)

$\mathbf{Z}_{im} \perp\!\!\!\perp U_{im} \mid (X_{im}, \mu_i)$,

- Above implies $L_{im} \perp\!\!\!\perp U_{im} \mid (X_{im}, \mu_i)$ because the randomness of L_{im} only comes from $\mathbf{Z}_{im}$ and μ_i.

Subscription Services



Theorem (Parametric Identification of WTP)

We have the following results when $U_{im} \mid (X_{im}, \mu_i) \sim \mathcal{N}(\sigma_{u,\mu}\mu^*_{im}, \sigma^2_u)$

1. *The unknown parameters* $(\beta, \sigma_u, \sigma_{u,\mu})$ *are identified.*
2. *The distribution of WTP is identified, and*

$$F_W(w \mid X_{im}, \mu_i, L_{im}) = \Phi\left[\frac{1}{\sigma_u}(\ln w - \ln L_{im} - \beta' X_{im} - \sigma_{u,\mu}\mu^*_{im})\right].$$

We do not need any parametric assumption like above.

What are the boundary conditions of this approach?

- **What happens without usage data? Subscription equation**

$$\begin{aligned} S_{im} &= \mathbb{I}(\ln L_{im} - \ln P + \beta' X_{im} + U_{im} > 0) \\ &= \mathbb{I}[(\beta_0 - \ln P) + \beta_1' X_{1im} + (\ln L_{im} + U_{im}) > 0] \end{aligned}$$

  Cannot distinguish between L_{im} and U_{im}

- Without exogenous shifters Z_{it}, again this approach will not work
- Need both usage data and exogenous shifters

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Estimation in a few easy steps

- **Estimate the usage model using finite mixture heterogeneity. Let $(\hat{\mu}_i, \hat{r}_{im}, \hat{\gamma}')$ be the estimates of (μ_i, r_{im}, γ')**
- Estimate monthly expected leisure L_{im} by substituting the unknown parameters (μ_i, γ') with the estimates $(\hat{\mu}_i, \hat{\gamma}')$. Denote this estimator by $\hat{L}_{im}$.
- For each month m, implement a linear regression of $\hat{\mu}_i$ on X_{im} and save the residuals $\hat{\mu}^*_{im}$. These residuals are the estimates of μ^*_{im}.
- Run the probit regression of S_{im} on $\ln(\hat{L}_{im}/P)$, X_{im}, and $\hat{\mu}^*_{im}$. The probit regression provides estimates of σ_u^{-1}, β/σ_u, $\sigma_{u,\mu}/\sigma_u$. Then the estimates of β and $\sigma_{u,\mu}$ are obtained easily.

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Is Usage Variation the Same as Price Variation

- **If we want to identify switching costs, no amount of usage variation is sufficient..**
  - **Why?**
- Consider a more general subscription choice with δ:

$$S_{im} = \mathbb{I}(\ln L_{im} - \ln(P_{im} - \delta' X_{2im}) + \beta_0 + \beta_1' X_{1im} + U_{im} > 0).$$

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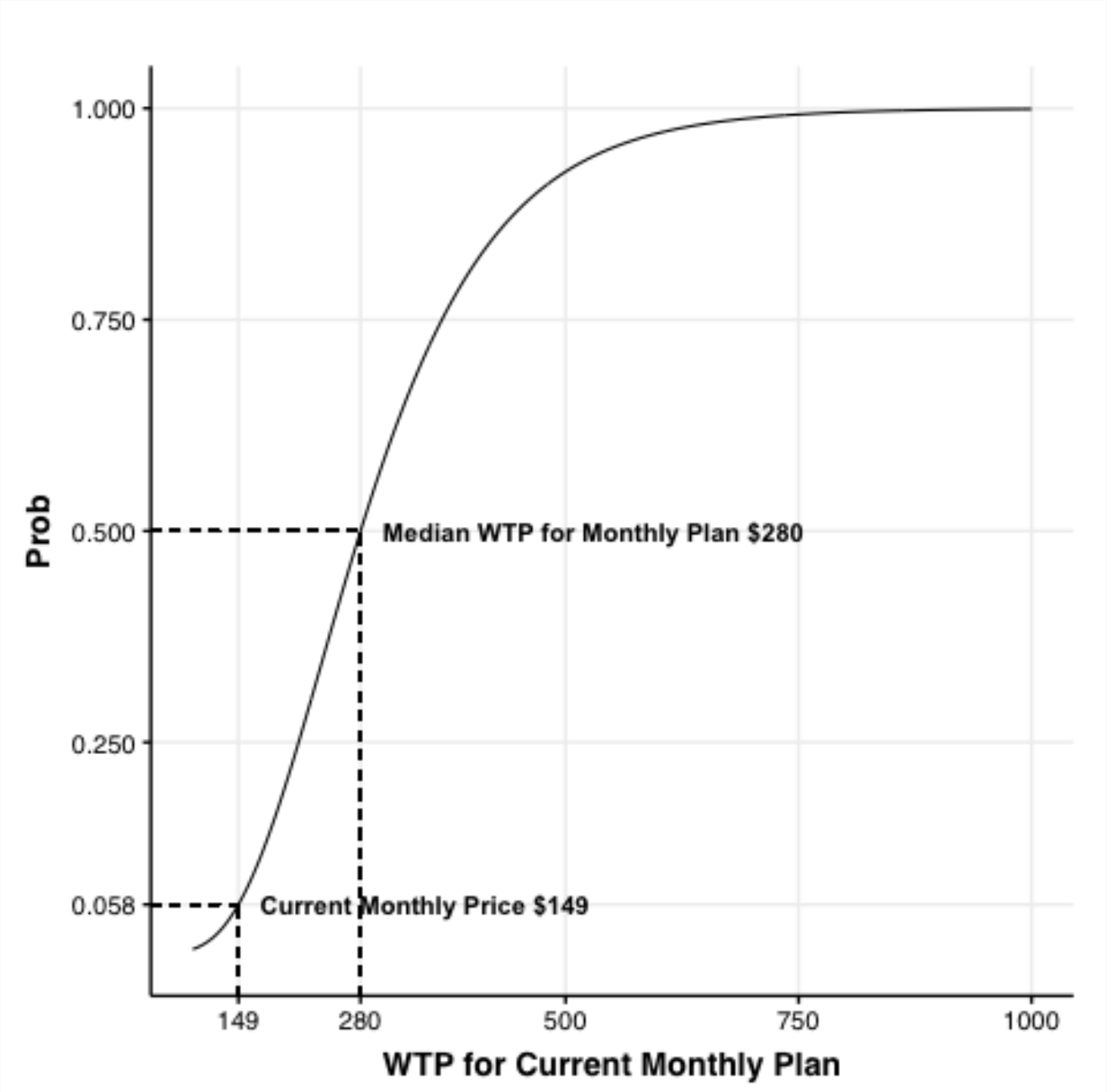
Empirical Application with Music Streaming

	All Users	Never Cancelled	Ever Cancelled
Monthly Usage (Hours)	41.73	44.25	18.48
	(50.65)	(52.07)	(24.76)
Daily Usage (Hours): Weekend	1.31	1.39	0.57
	(2.21)	(2.27)	(1.41)
Daily Usage (Hours): Weekdays	1.39	1.47	0.62
	(2.28)	(2.35)	(1.30)
Age	30.91	31.12	29.69
	(9.09)	(9.32)	(7.56)
Female (%)	42.00	42.35	40.00
Number of Users	300	255	45

Empirical Application with Music Streaming



Empirical Application with Music Streaming

	Parameters	Estimates	Std Err
Usage eq.	$\mu_{Type\,1}$	0.8279	(0.0471)
	$r_{Type\,1}$	2.1130	(0.1566)
	$\gamma_{Holiday,Type\,1}$	0.0297	(0.0157)
	$\gamma_{Weekend,Type\,1}$	0.0257	(0.0142)
	$\mu_{Type\,2}$	0.8339	(0.0539)
	$r_{Type\,2}$	5.3138	(0.9502)
	$\gamma_{Holiday,Type\,2}$	−0.0365	(0.0223)
	$\gamma_{Weekend,Type\,2}$	−0.0369	(0.0251)
	$\gamma_{Humidity}$	−0.0010	(0.0005)
	$\gamma_{Precipitation}$	0.0004	(0.0002)
Subscription eq.	β_0/σ_u	5.9226	(1.4853)
	$1/\sigma_u$	2.5261	(0.7895)
	β_{Age}/σ_u	0.0115	(0.0039)
	β_{Female}/σ_u	0.1095	(0.0698)
	$\sigma_{u,\mu}/\sigma_u$	−6.2721	(4.0592)

Empirical Application with Music Streaming

Segment	Price Elasticity		Revenue Max Price	Mean Usage	Median WTP ($)
All Users	−0.31	(0.10)	206	1.37	280.00
Male	−0.33	(0.11)	202	1.43	275.00
Female	−0.27	(0.08)	212	1.29	288.00
Age ≤ 22	−0.37	(0.13)	197	1.45	268.00
Age 23–30	−0.34	(0.11)	201	1.55	273.00
Age > 30	−0.26	(0.08)	214	1.22	290.00

Empirical Application with Music Streaming

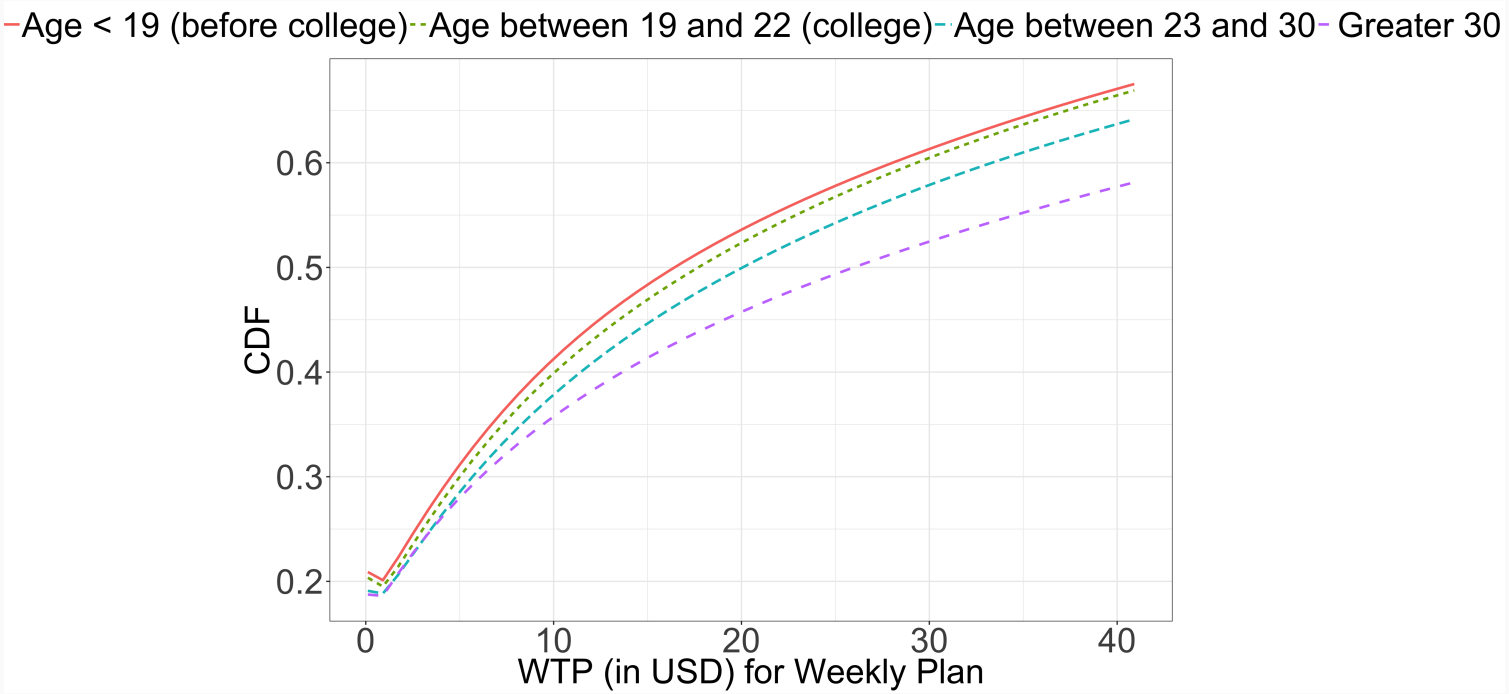
User Groups	Humidity Only	Precipitation Only	Both
All Users	−0.307	−0.367	−0.366
	(0.098)	(0.106)	(0.105)
Male	−0.332	−0.397	−0.396
	(0.111)	(0.122)	(0.121)
Female	−0.273	−0.326	−0.325
	(0.083)	(0.090)	(0.089)
Age ≤ 22	−0.368	−0.439	−0.437
	(0.129)	(0.142)	(0.141)
Age 23–30	−0.339	−0.405	−0.403
	(0.114)	(0.125)	(0.124)
Age > 30	−0.261	−0.313	−0.312
	(0.078)	(0.083)	(0.083)

Empirical Application with Music Streaming

	All Users	Never Cancelled	Ever Cancelled
Monthly Usage (Hours)	41.73	44.25	18.48
	(50.65)	(52.07)	(24.76)
Daily Usage (Hours): Weekend	1.31	1.39	0.57
	(2.21)	(2.27)	(1.41)
Daily Usage (Hours): Weekdays	1.39	1.47	0.62
	(2.28)	(2.35)	(1.30)
Age	30.91	31.12	29.69
	(9.09)	(9.32)	(7.56)
Female (%)	42.00	42.35	40.00
Number of Users	300	255	45

Empirical Application with Music Streaming

WTP variation with age / college status



Can we design shorter plans? Segmentation by duration

- **Shorter subscription plan based on higher frequency usage data**
  - **Desire a plan of shorter length**
  - **What's the distribution of the WTP for the shorter plan?**
- Evaluate the money-metric effect of product changes
- Identify interesting new mechanism for longer duration plans
  - Shorter plans allow flexibility and could increase consumer WTP
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    - Make it easier to extract surplus

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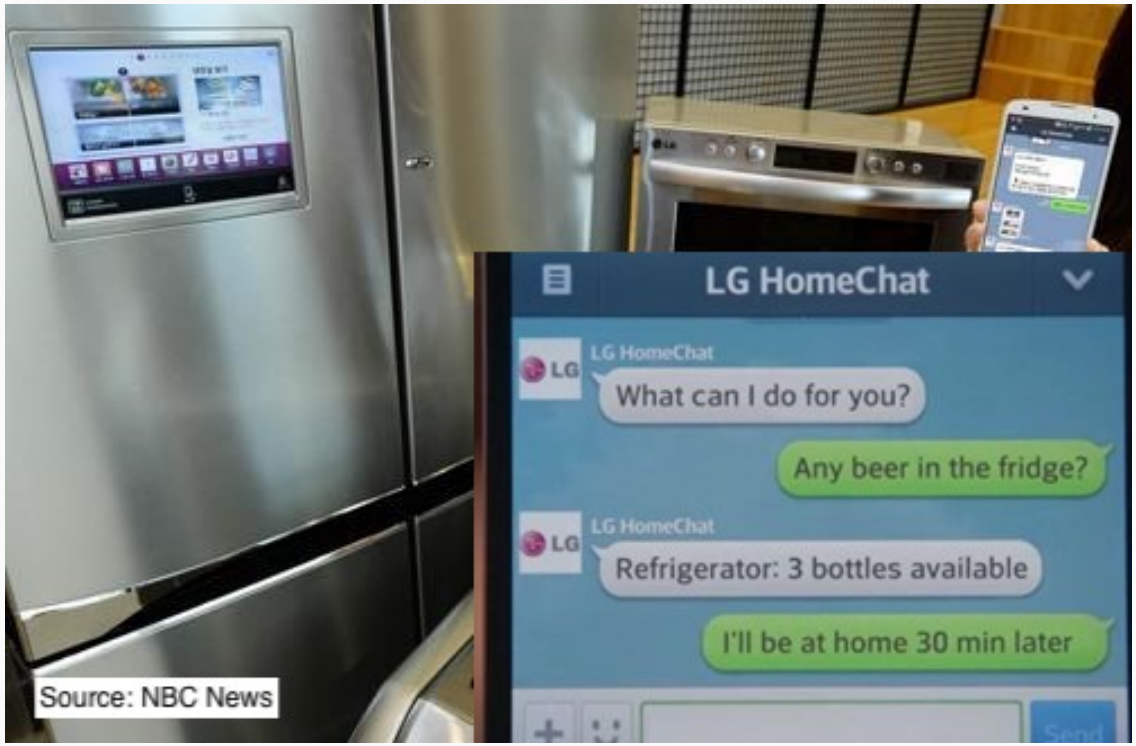
Conclusions

Without Price variation, can we obtain WTP?

- **A: Qualified Yes.**
- What big data on usage tracking **can tell** us?
  - The distribution of WTP under some restrictions
- Can design counterfactual products and pricing strategies
- Cannot replace the role price variation, even limited, in identifying switching costs

A bigger picture (of a fridge)



- Essentially, we need the separation of purchase (subscription) and consumption (usage).
- Such separation also holds in packaged goods (beer)—but we did not track the usage.
- 5G and Internet of Things could enable such tracking.

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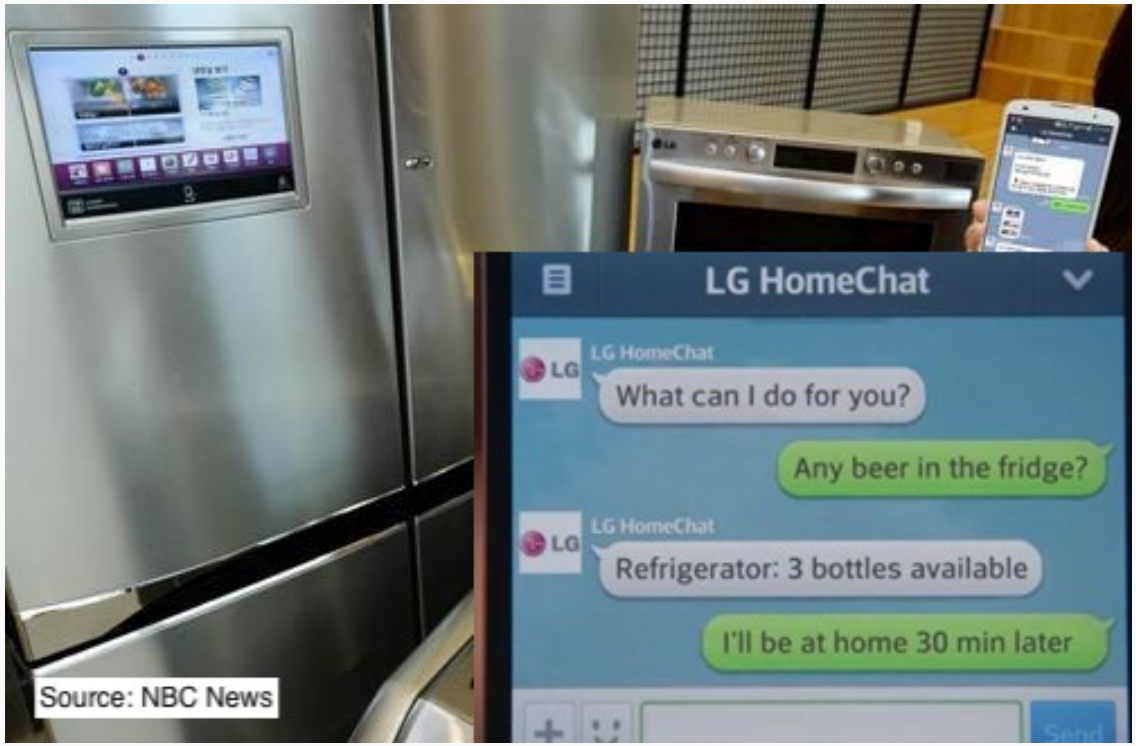

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My Research Overview

- Substantive: Digital Business Models
- Methodological: Structural Models $\Longleftrightarrow$ Machine Learning
  - Different approaches to ML

Some projects:

- Nonparametric Bandits Leveraging Informational Externalities to Learn the Demand Curve, with Ian Weaver (Major Revision at Marketing Science)
- Automatically Discovering Visual Product Characteristics, with Ankit Sisodia and Alex Burnap (Revision at Journal of Marketing Research)

ADDITIONAL SLIDES