Demand Estimation for Subscription Models

Identifying Willingness to Pay without Price Variation

Vineet Kumar

Yale University, USA

Summer Institute in Competitive Strategy

UC Berkeley, CA

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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**

Subscription Services

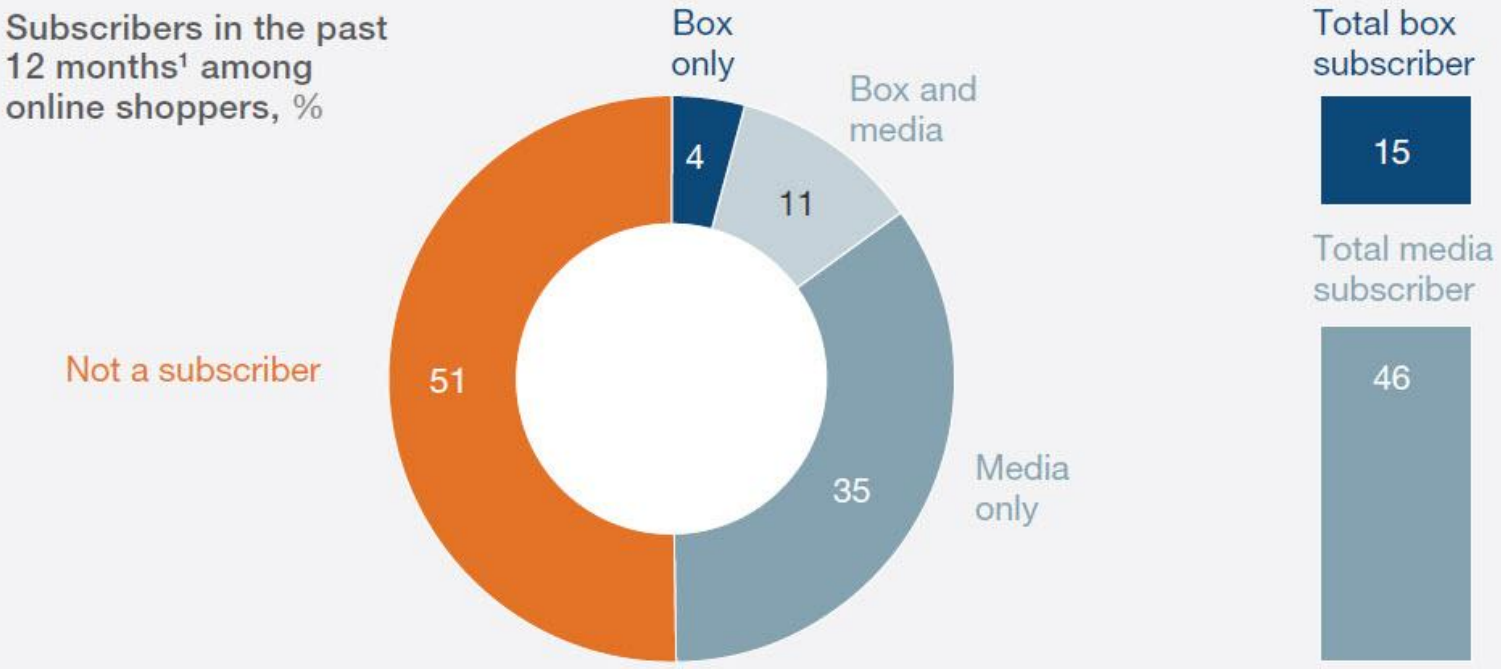
Frontier Airlines Now Has an Unlimited Pass for Summer — Here's How to Score One

"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

Subscription Services

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

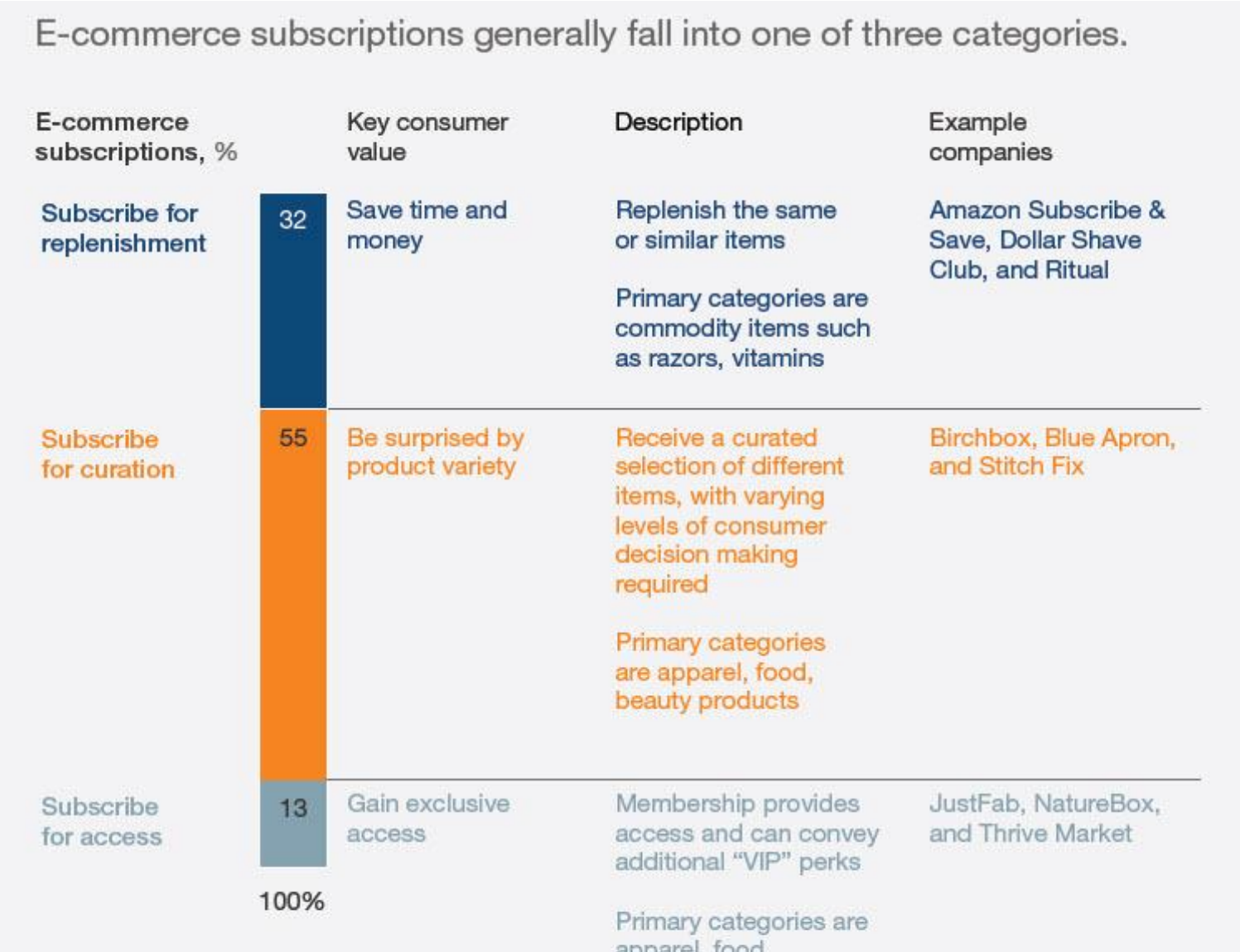


Note: Figures may not sum to 100%, because of rounding.

[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 Services

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	–

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  - Elasticities

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What's common to above?

All these cases have price variation!

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Big Picture Idea:

Leverage high frequency usage data for identification.

Usage is captured at higher frequency than purchase.

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  - Gentzkow (2007)...

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Focus:

Obtain WTP estimates for a subscription service with high frequency usage data

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More specifically:

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

With Price Variation – Notation

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:

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

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

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

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

Model Overview and Elements

Should we model greater utility and WTP with greater usage?

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

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

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

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}:

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- Monthly expected leisure $L_{im} \equiv \sum_{t:m(t)=m} (\mu_i + \gamma' Z_{it})$

Characterization of Value of 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*

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

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 $X_{im}' = (1, X_{1im}')$.

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

$$S_{im} = \mathbb{I}(\ln L_{im} + \beta' X_{im} - \ln P + U_{im} > 0).$$

Exogenous Variation

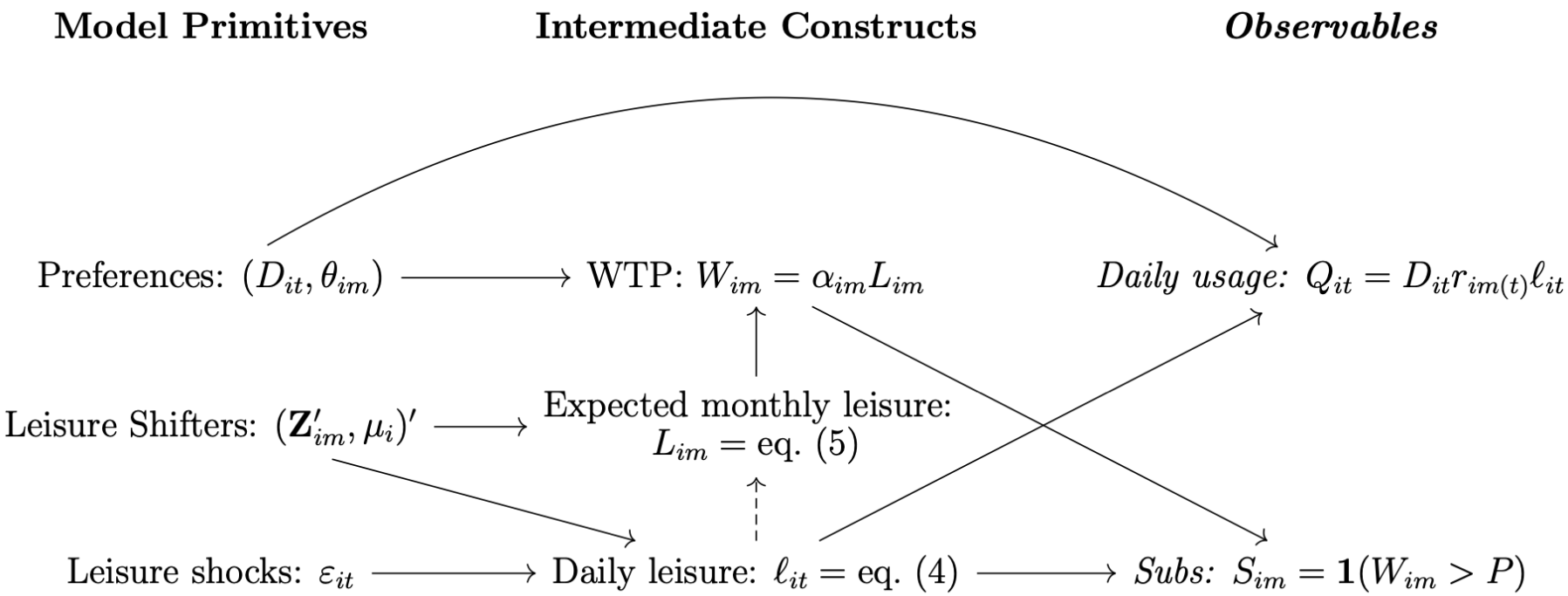
What exogenous variations are required for identification?

Assumption (Exogenous Variation)

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

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

Model Components – Overview



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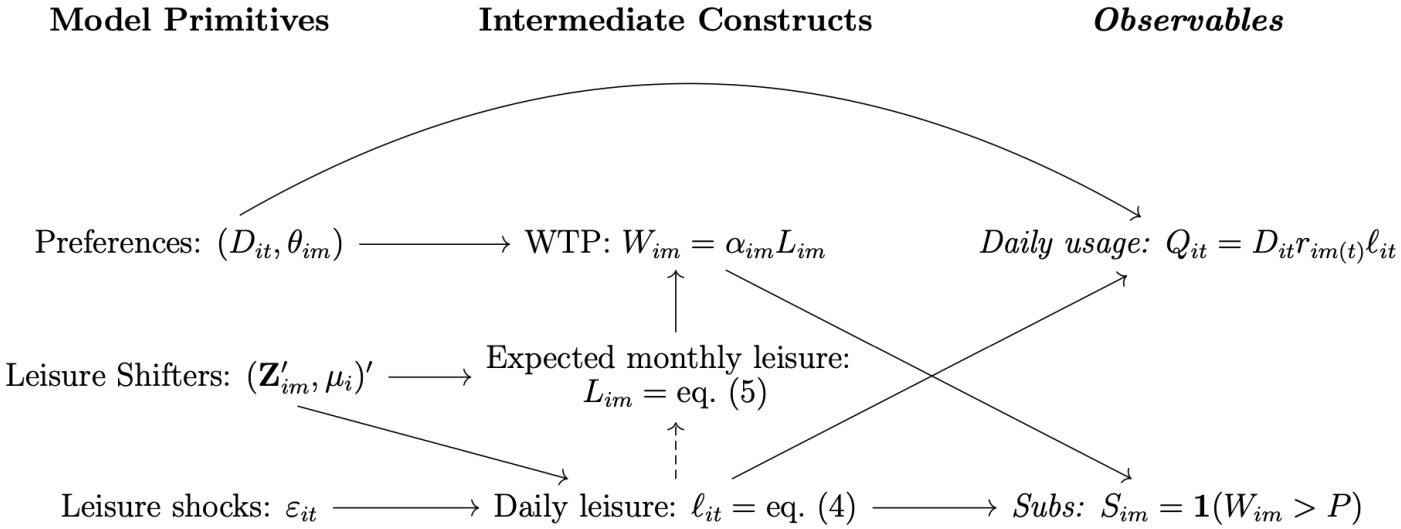

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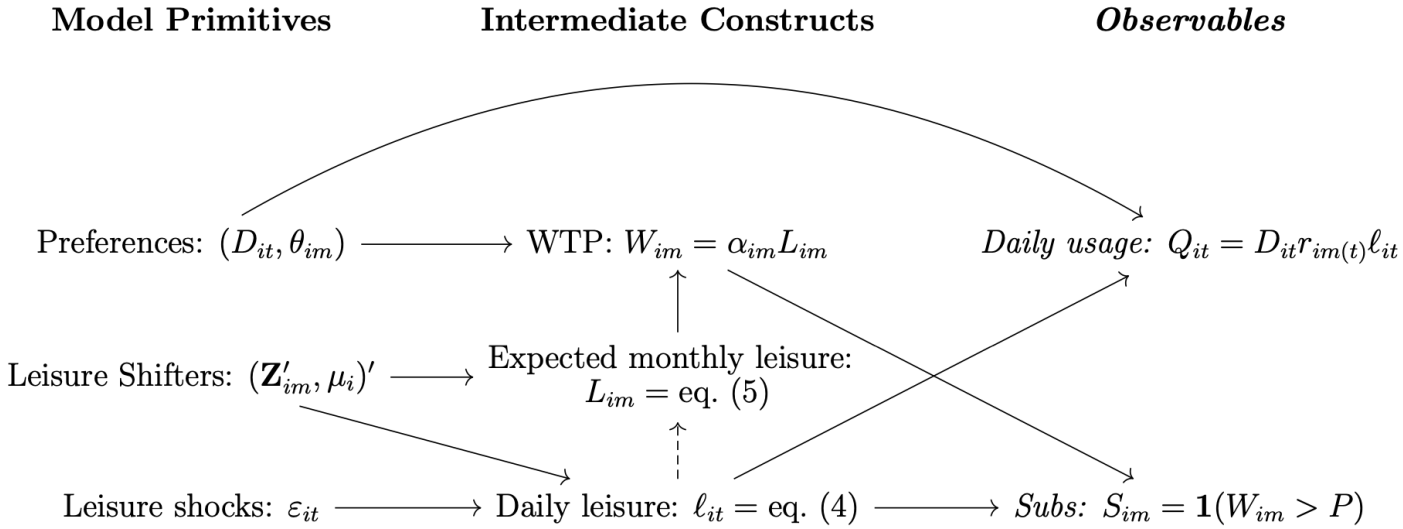

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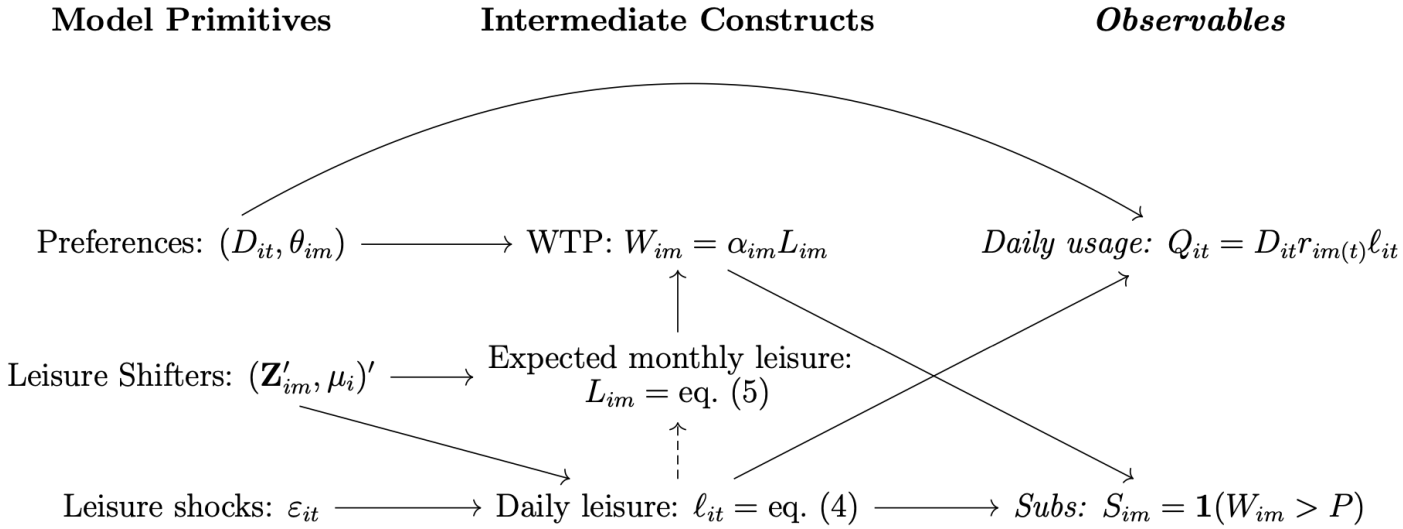

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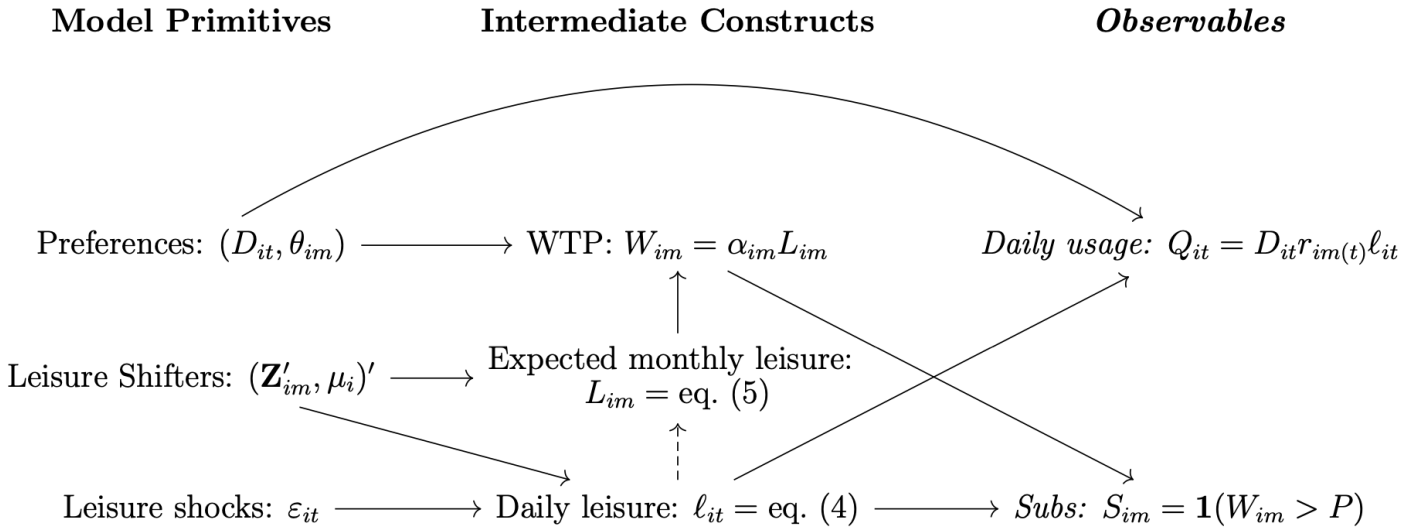

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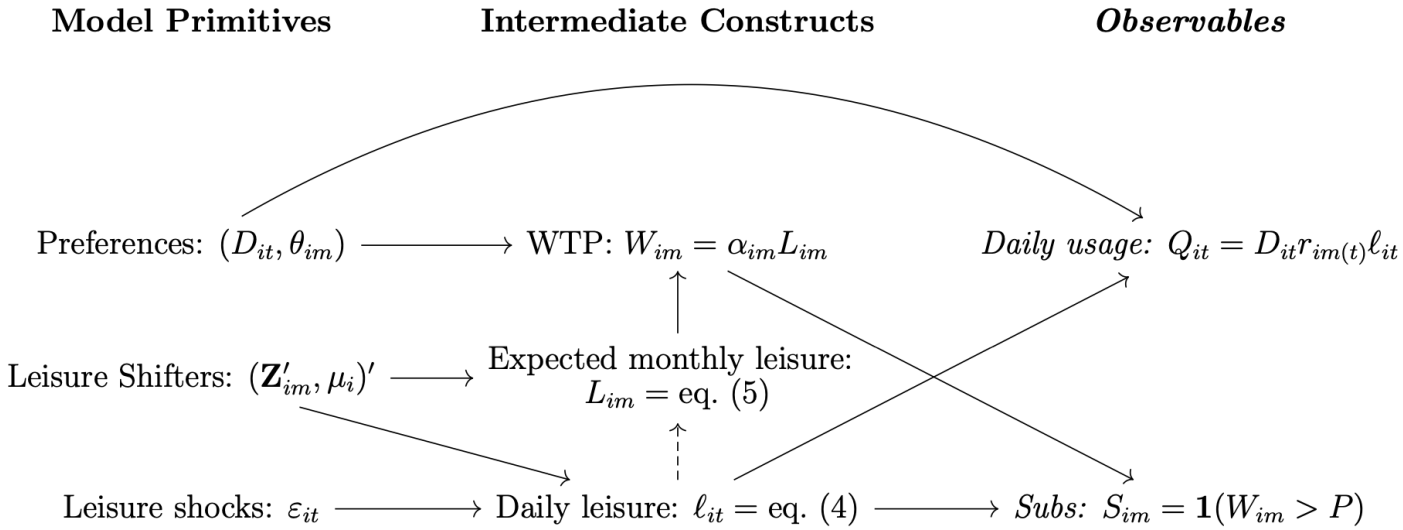

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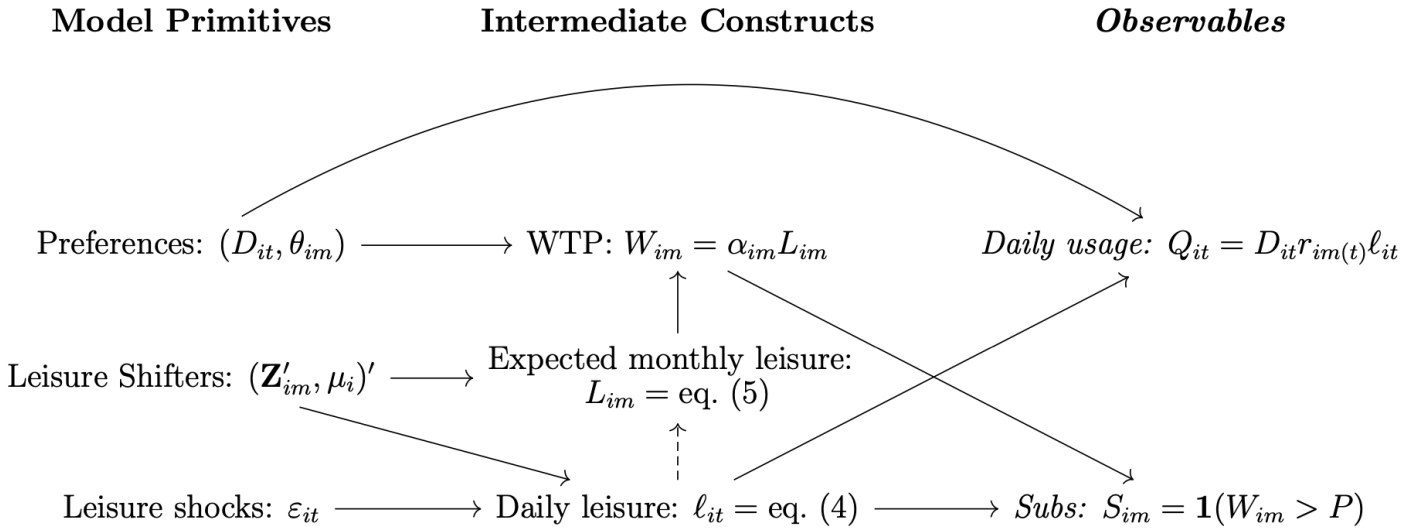

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  - Aggregate Leisure + Consumer-level variables (vary across consumer and time) $\Longrightarrow$ Purchase

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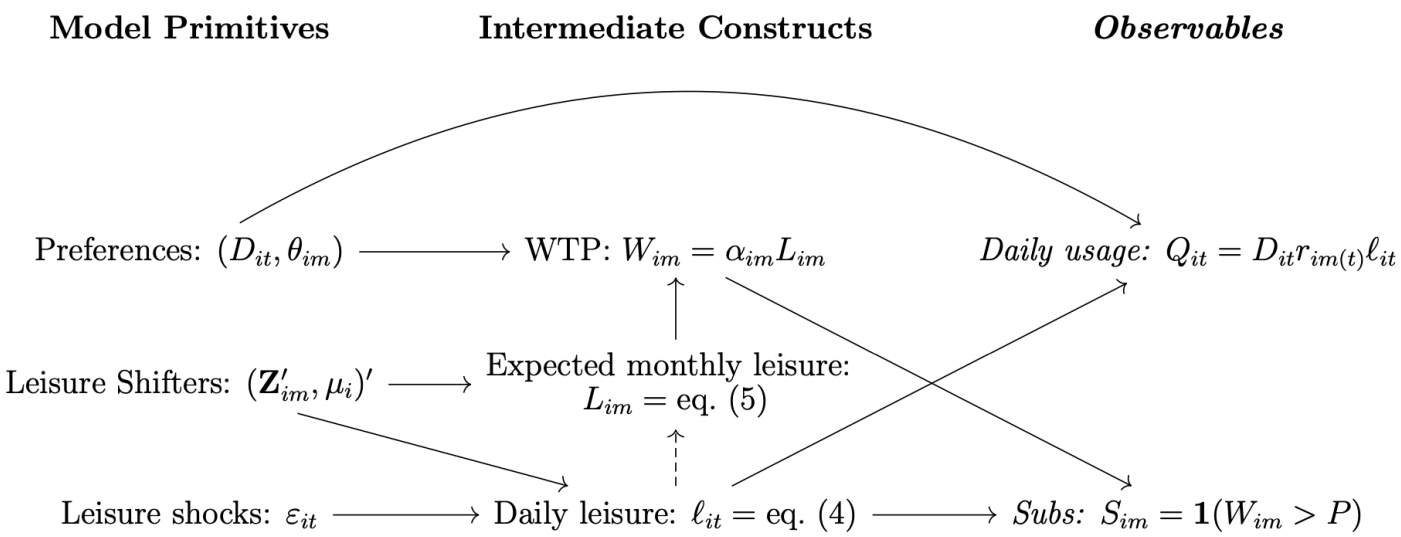

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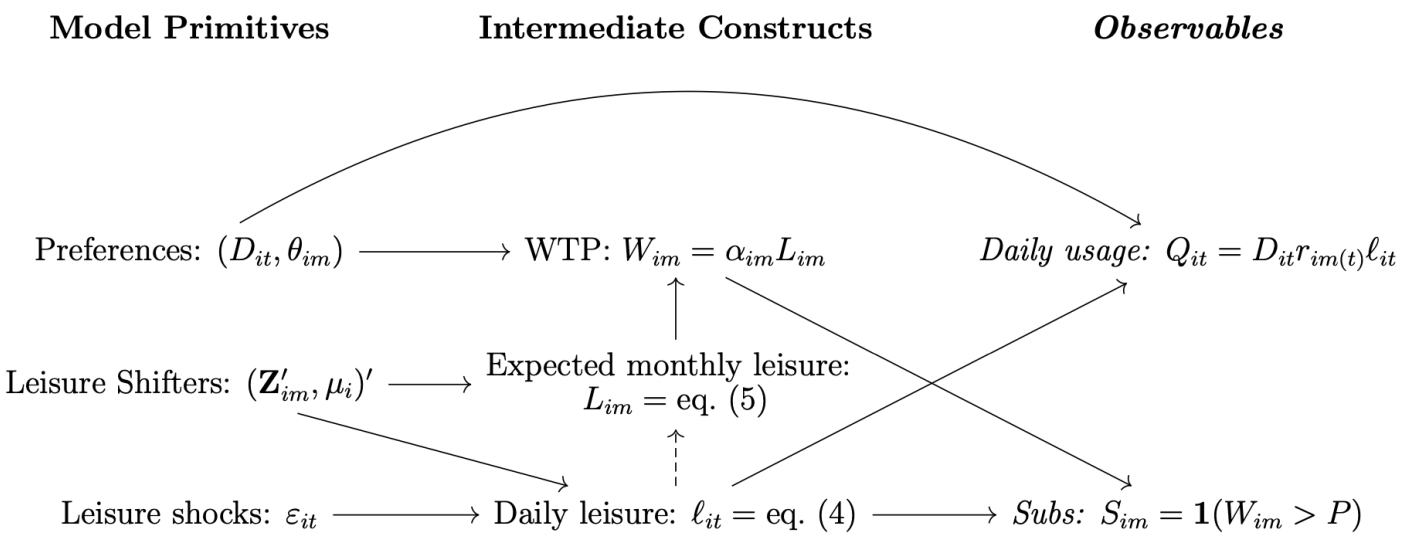

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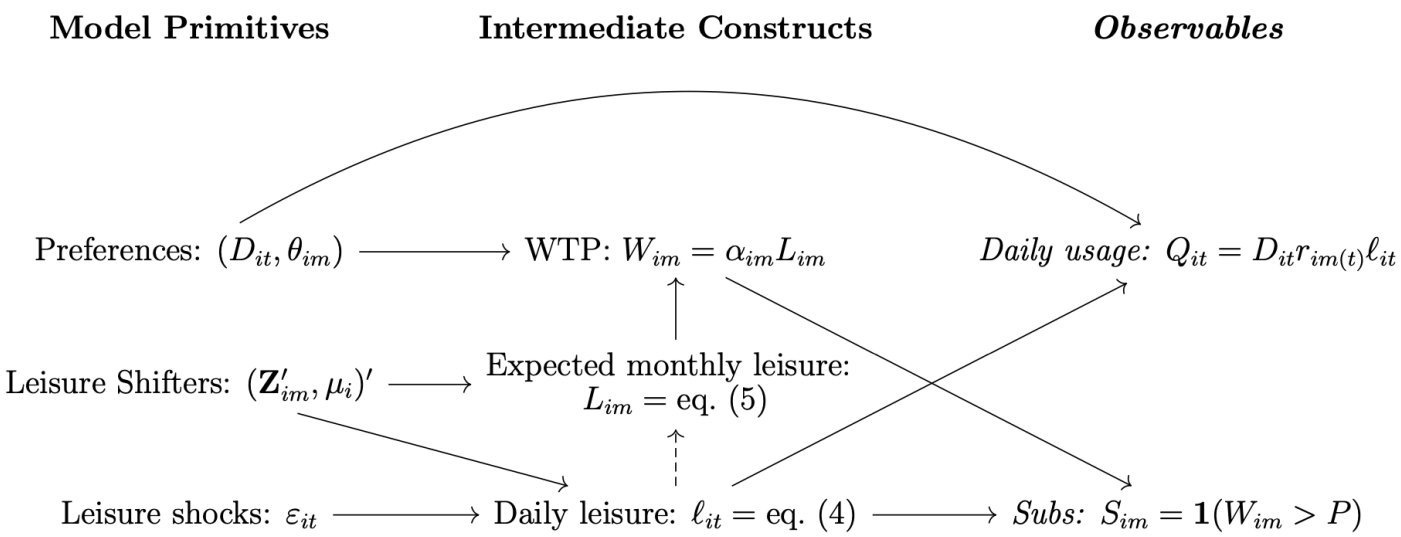
  - Usage: Unobservable heterogeneity captured by μ_i

Model Components – Overview



- We capture across consumer heterogeneity in a couple of ways:
  - Usage: Unobservable heterogeneity captured by μ_i
  - Purchase: Observed heterogeneity captured by X_{im} and Unobserved heterogeneity by U_{im}

Main Result

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*

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

We do not need this parametric assumption above.

Boundary conditions of method

- What happens without usage data? Subscription equation

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

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

Is Usage Variation the Same as Price Variation

- If we want to identify switching costs, no amount of usage variation is sufficient..

Switching Cost

Need at least 2 price levels to identify switching cost.

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  - 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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- **Step 2:** 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 $\hat{L}_{im}$.

Estimation – Subcription

WTP for the service: $W_{im} = \alpha_{im} L_{im}$

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

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- **Step 4:** 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.

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

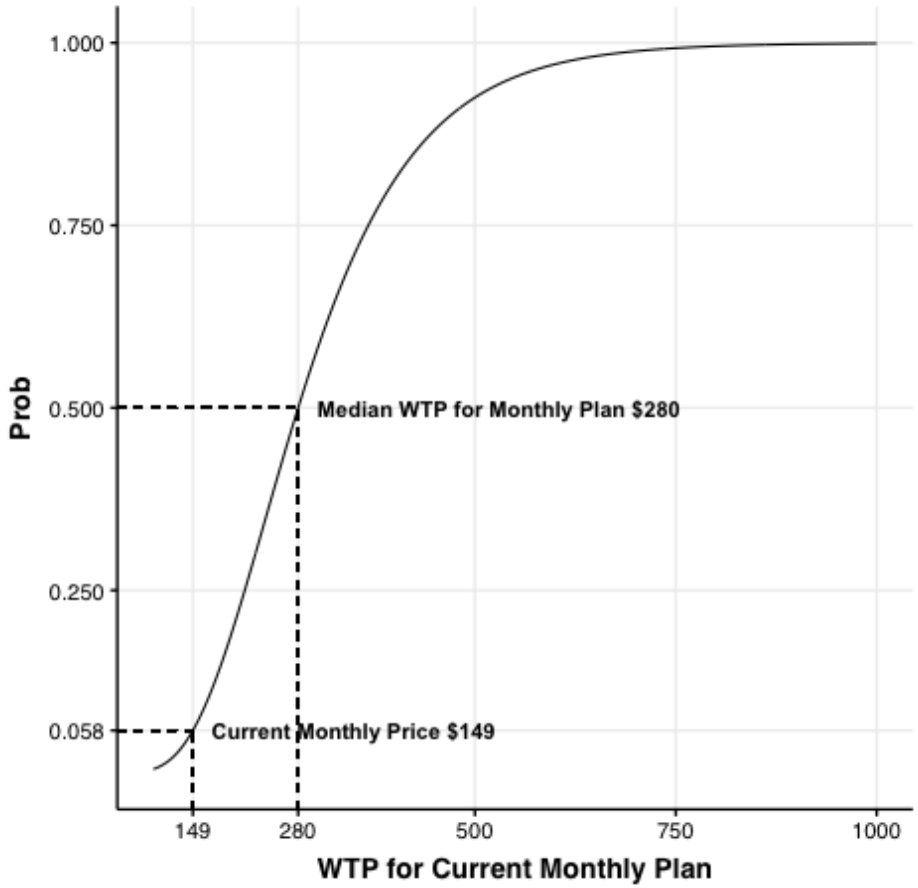

Figure: Estimates of the Distribution of WTP for the Monthly Plan

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 $\leq$ 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)

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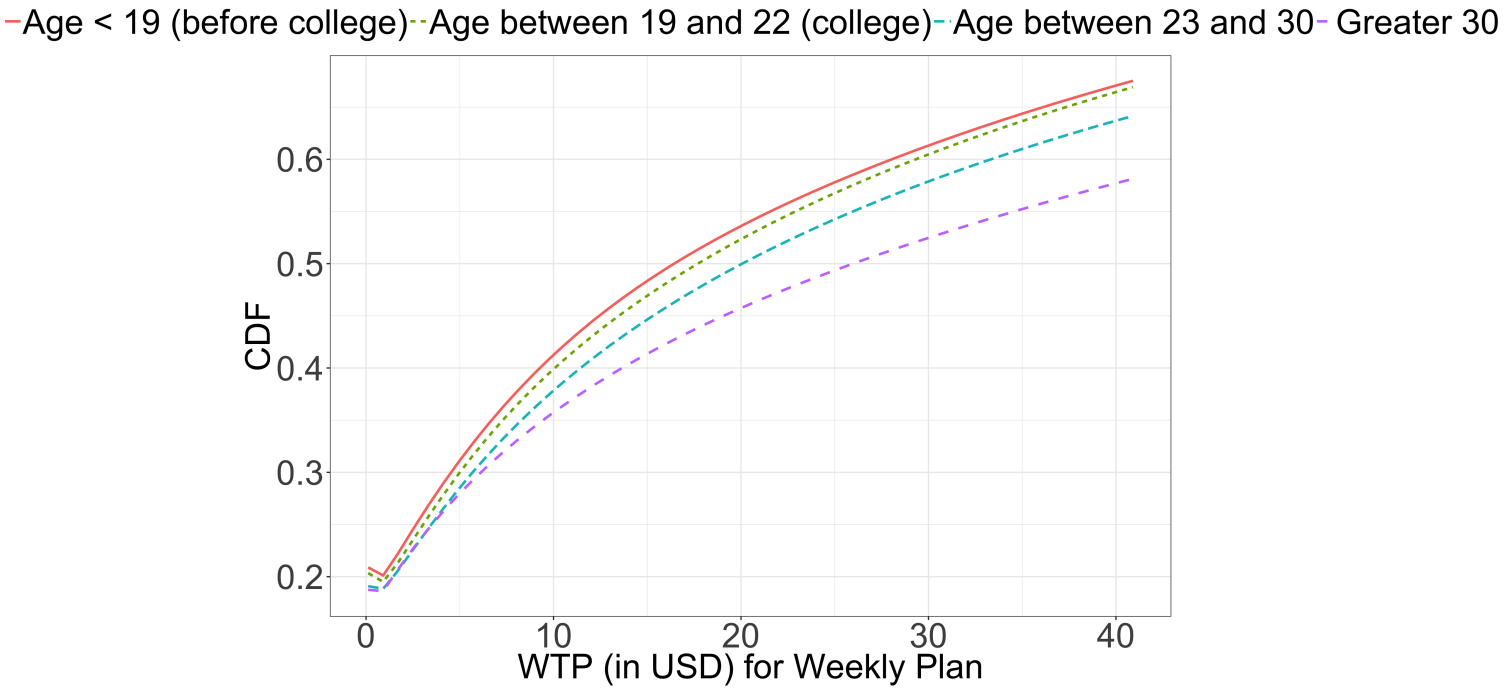
WTP variation with age / college status



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 of price variation, even limited, in identifying switching costs

Strategic Plan Duration

Duration as a segmentation device

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- When does it work well and when does it not?

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Identify interesting mechanisms based on plan duration

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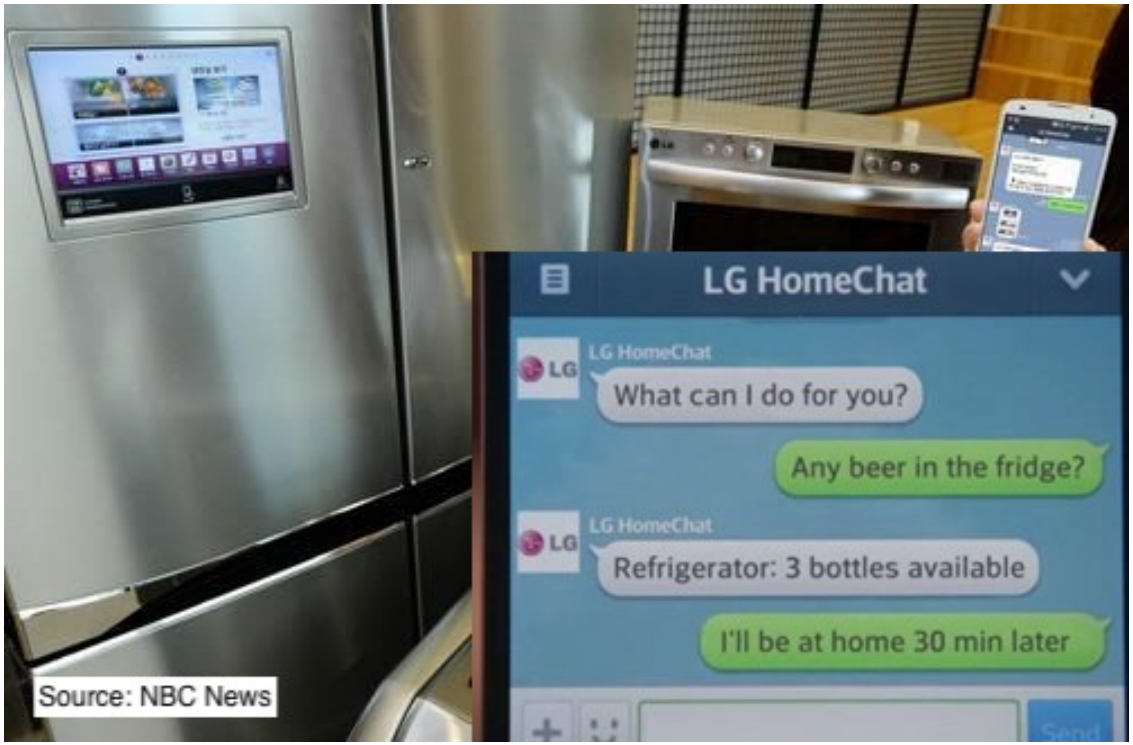
  - But, wait ... including 3rd month $\Longrightarrow$ heterogeneity $\uparrow$
- Can we characterize the optimal duration as a function of heterogeneity distribution?

A bigger picture (of a fridge)



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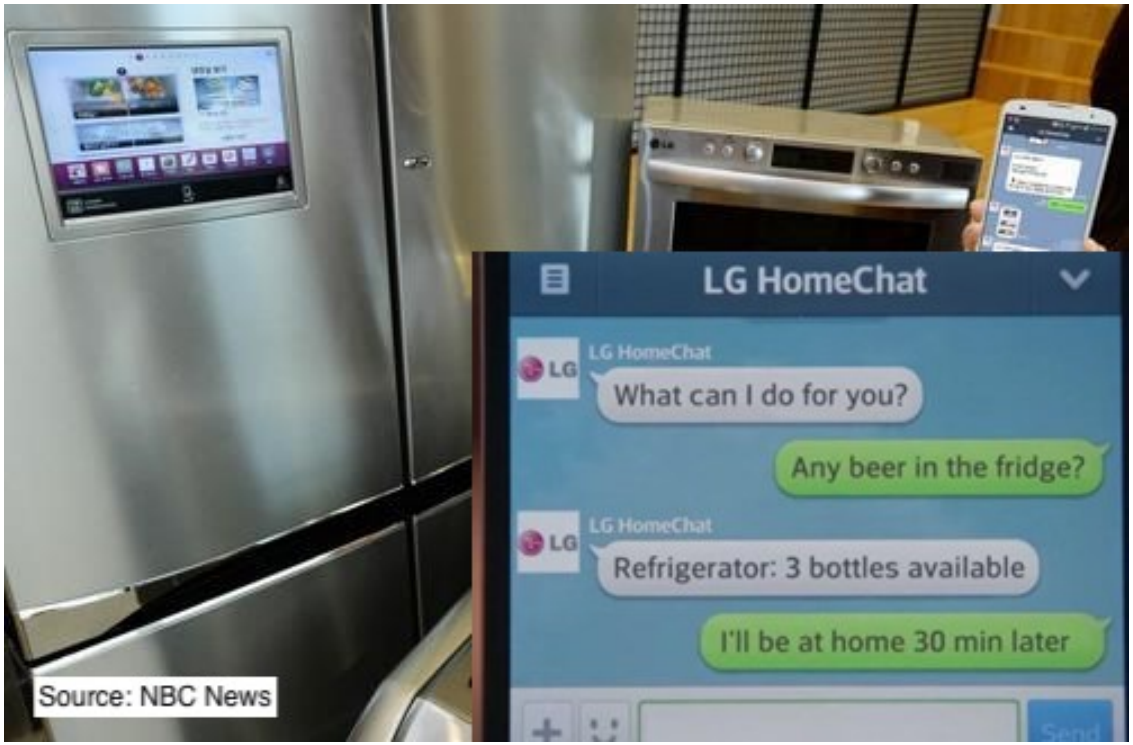

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- Such separation also holds in packaged goods (beer)—but we did not track the usage.