Senior Transit Subsidies and Welfare

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Motivation

Public transit: substantial share of inland travel (17% EU, 34% Japan, 28% Korea)

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Higher stakes with population aging + fiscal burden

Yet most existing studies focus on transport policy for the general population, **not seniors**

What We Do

Our Questions

- What are the actual impacts of Greater Seoul's free subway policy for seniors?

Empirical Strategy

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- Demand Estimation & Simulations

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  - Capture equilibrium effects of the policy (congestion feedback)
  - Evaluate welfare effects of current & counterfactual policies

What We Find

Current policy (Free Subway):

- Subway rides $\uparrow$ 0.04 (16.3%) per day; peak-hour congestion $\uparrow$ 2%
- Half from bus substitution; little from car
- Regressive: top decile benefit $8\times$ bottom decile
- Inefficient: ₩112b ($\simeq$USD 80m) annual loss (price distortion & congestion)
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Better alternative: CS-equivalent Discount for **Bus** & Subway (₩564 ≃ USD 0.4)

- Improves efficiency by 34%
- Improves equity (better serves low-SES seniors)
- Dominates current policy across plausible distributional pref. & uninternalized benefits

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Optimal policy: Depends a lot on inter-generational distributional weights

Context and Data

Policy Background

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Why controversial now?

- Senior share now 18% (2024) vs. 3% (1980)

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- Rising fiscal burden (≃USD 290m/yr) & more (claimed) subsidy-led subway congestion

Main Data: KT's Origin-Destination Level Mobility Data

- Measure individuals' transportation use
  - Based on cellphone signal movements between cellular base stations
  - Hourly number of trips made by subways, buses, and cars (including both personal cars and taxis) for each OD x hour
  - Covers mobility of $\underbrace{\text{Greater Seoul}}_{\text{Seoul, Gyeonggi, Incheon}}$ residents during June to August, 2023
  - Provided by KT, 2nd-largest mobile carrier in Korea with a 30% market share
- Link individuals' age (in year) to the each cell phone trip more details

Other Data Details

- Stated Preference Surveys
  - Measure individuals' WTP for congestion
  - Choose a trip plan and transportation mode under hypothetical levels of congestion and price for each mode
  - Not used for RDD; used for demand estimation and simulations
- Other data for testing RDD assumptions

Regression Discontinuity Results

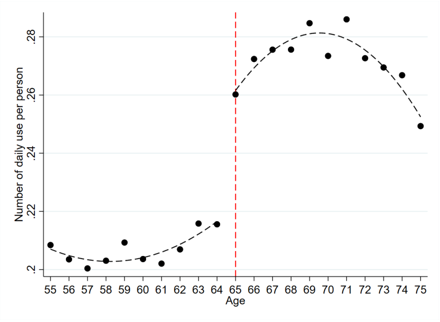
Regression Discontinuity Design

- RD: free subway subsidy starts at 65
- Outcomes: Demand for transportation modes
- Identifying assumption: Outcomes are continuous absent the subsidy
  - Other discontinuities at 65: minor copay change, basic pension
  - No evidence of confounding. For example, labor supply shows no sharp discontinuity at 65:

labor supply (appendix) healthcare use (appendix) consumption (appendix)

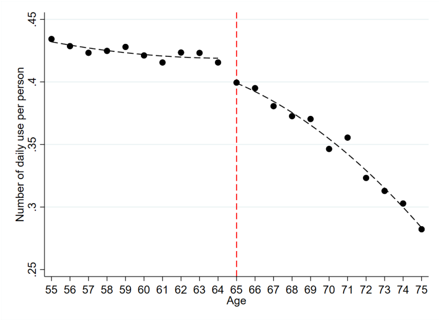
Free Subway → More Subway, Less Bus

Subway



Discontinuity (S.E.) = 0.040 (0.004)***

Bus



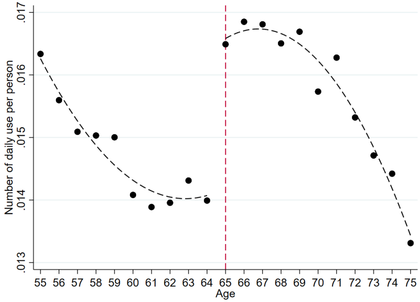
Discontinuity (S.E.) = -0.02 (0.005)***

Data source: KT's OD Level Mobility Data
Notes: We restrict the sample to those aged 55 and 75. To estimate discontinuities at age 65, we use the equation (1).

Free Subway → More Subway, Less Bus

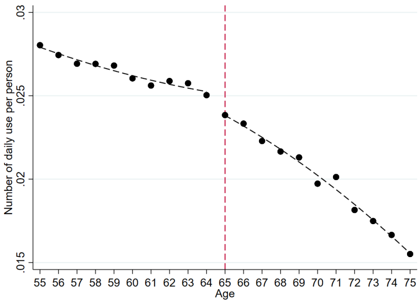
During Peak Hours

Subway



Discontinuity (S.E.) = 0.002 (0.0001)***

Bus



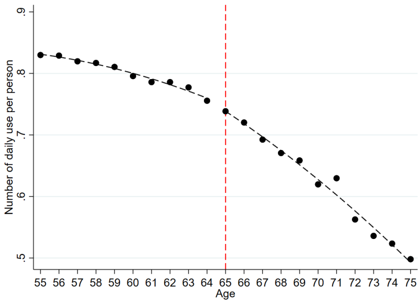
Discontinuity (S.E.) = -0.001 (0.0001)***

Data source: KT's OD Level Mobility Data

Notes: We restrict the sample to those aged 55 and 75. To estimate discontinuities at age 65, we use the equation (1). The peak times include 7-9am or 5-7pm.

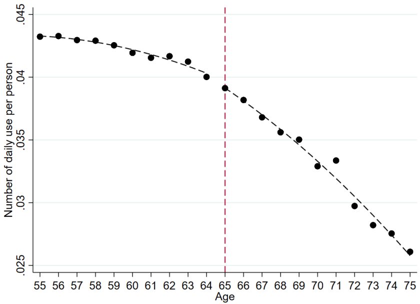
Little Response in Car Rides

Any time



Discontinuity (S.E.) = -0.010 (0.007)

During peak hours



Discontinuity (S.E.) = -0.001 (0.0004)**

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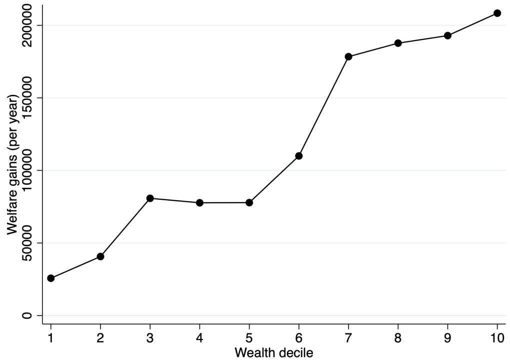
High SES Benefits the Most

under linear demand and ignoring congestion effects



Data source: KT mobility data 2023 and Seoul Commercial District Analysis Service
Notes: We restrict the sample to those aged 55 and 75. To estimate discontinuities at age 65, we use the equation (1). We define wealth level by using information on residential area's land price. The monthly welfare gain for seniors at age 65 was calculated using a linear demand function.

Economic Model Results

Isn't RDD enough?

RDD analyses:

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- Enables design & evaluation of counterfactual policies

Empirical Model: Transportation Mode Choices

Hierarchical nested logit model utilities estimates model fit

- At a given hour, each individual chooses between: Subway, Bus, Car, Outside Option
- Allows for mode-age level unobserved demand shocks $\rightarrow$ endogeneity
- Features disutility from congestion (crowding)
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Why endogeneity:

- Even when prices are assumed exogenous (set by gov)...
- Closed-form for HNL: RHS has within-nest shares, *function* of unobserved demand shocks

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Stated preference surveys: WTP for reduced congestion other data

Welfare Framework

$$SW = CS + G + UB$$

Welfare Framework

$$\underbrace{SW}_{\text{Social Welfare}} = CS + G + UB$$

Welfare Framework

$$SW = \underbrace{CS}_{\text{Consumer Surplus (incl. disutility from congestion)}} + G + UB$$

Welfare Framework

$$SW = CS + \underbrace{G}_{\text{Net Governmental Revenue}} + UB$$

Welfare Framework

$$SW = CS + G + \underbrace{UB}_{\substack{\text{Uninternalized Benefit} \\ \text{(externalities other than} \\ \text{congestion \& own benefits not} \\ \text{fully valued)}}}$$

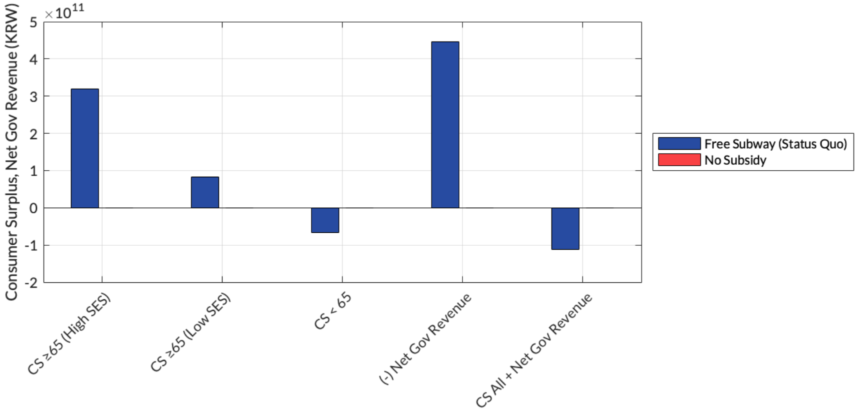
Welfare Framework

$$SW = CS + G + UB$$

But UB is hard to quantify $\rightarrow$ so consider $UB = 0$ *for now*, come back to this in later slides

Social Welfare: Free Subway Policy

Ignoring Uninternalized Benefits



CS-equiv Equal Discount for Bus & Subway Cuts Welfare Costs By 34%

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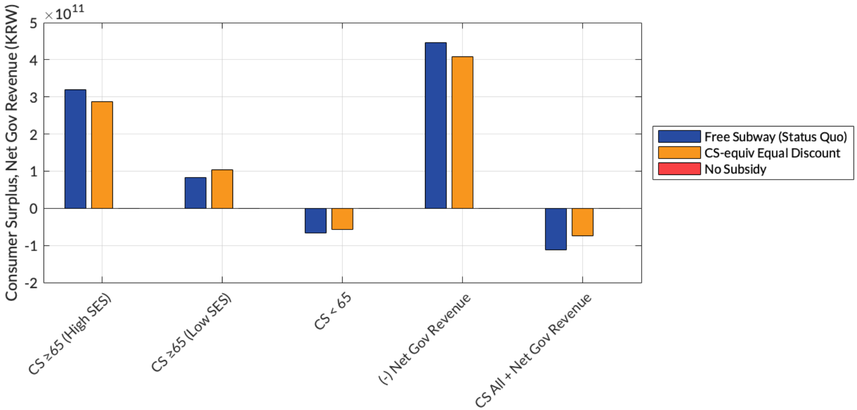
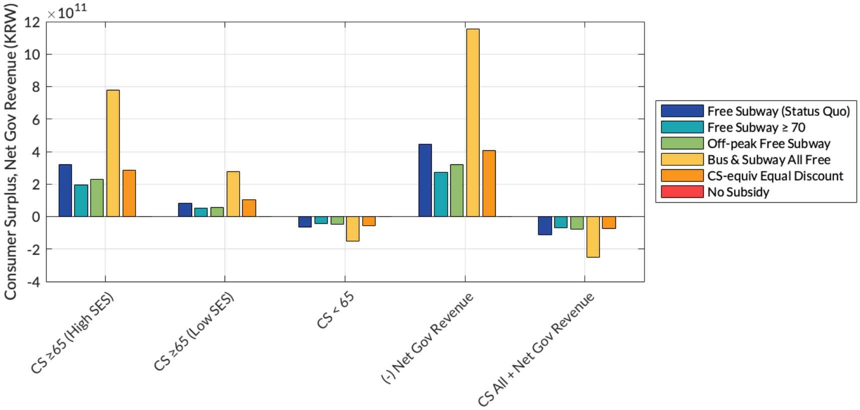


Equal discount (564-won ≃ 40%) also reduces regressivity (low-SES group has relatively more access to buses)

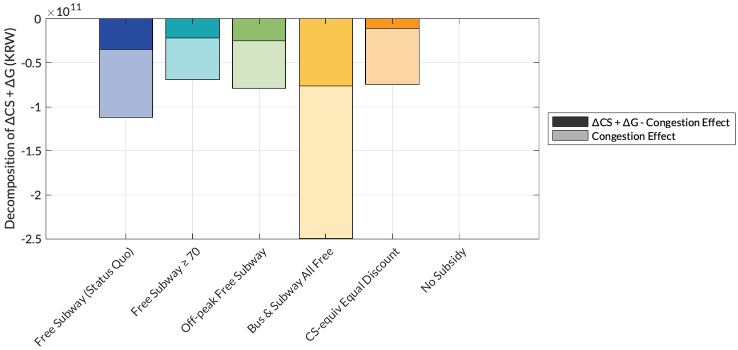
Social Welfare Comparison Across Policies

Ignoring Uninternalized Benefits



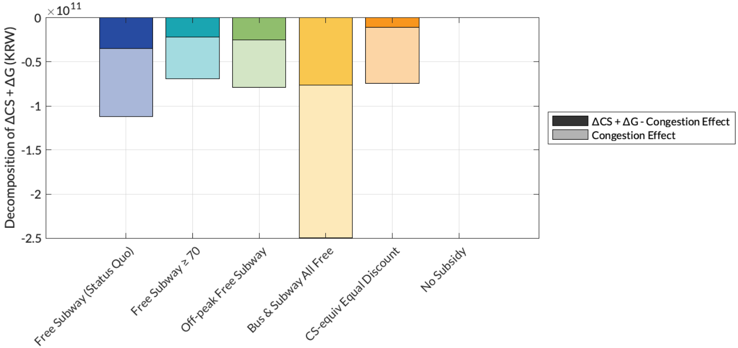
Free Subway: Congestion Leads to Welfare Loss

Ignoring Uninternalized Benefits



Equal Discount: Nearly Eliminates DW Loss (excl. congestion cost/UB)

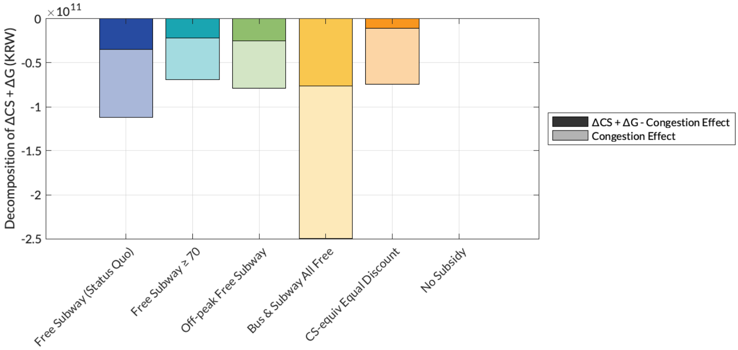
Ignoring Uninternalized Benefits



Equal discount reduces 1. relative price distortions 2. congestion costs

No Subsidy Dominates, But...

Ignoring Uninternalized Benefits



Adding Uninternalized Benefits and Distributional Weights

$\omega := (\omega_y, \omega_l, \omega_h)$: Weights for young, low-SES, and high-SES elderly

υ: Uninternalized benefit per a visit using transportation

$$SW(\omega, \upsilon) = CS(\omega) + G + UB(\omega, \upsilon)$$

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υ: Uninternalized benefit per a visit using transportation

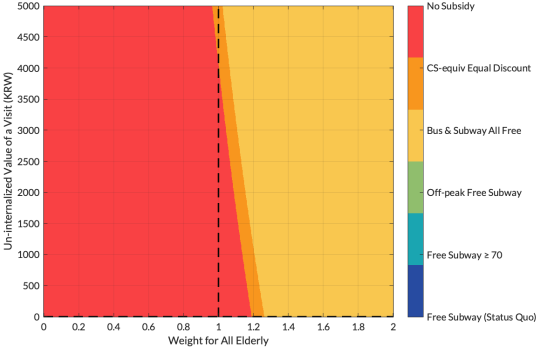
$$SW(\omega, \upsilon) = CS(\omega) + G + UB(\omega, \upsilon)$$

We don't take a stance on (ω, υ).
Rather, we discuss:

- Optimal policy as a function of (ω, υ)
- Robust policy regardless of (ω, υ)

Optimal Policy, given $SW(\omega, \upsilon)$

Varying weights on all elderly vs. young

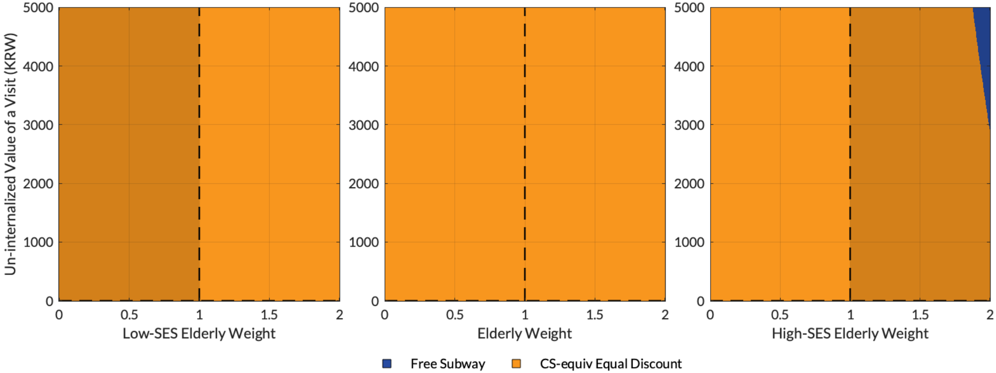


- Free Subway: never optimal
- Common feature of optimality: no relative price distortion
- Optimal discount amount: depends mostly on elderly weights

low-ses elderly weights

Free Subway Is Dominated by Equal Discount

under plausible (unshaded) region



Free Subway only better under large high-SES elderly weights

Conclusion

Takeaways

Important: large share of travel, elderly subsidies common, rapid aging

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Our findings:

- Free subway rides increase subway use but do not reduce car use
- Policy leads to substantial congestion costs and fiscal burden
- Current policy is never optimal for any (ω, υ) and is dominated by...

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- An 564-won discount for bus & subway: improves equity and cuts efficiency costs by 34%
  - Intuition: reducing price distortion, congestion costs and better targeting low-SES
- Discount amount may be adjusted depending on intergenerational equity concerns

Contributions to the Literature

Transit Subsidies, Welfare, and Distribution. e.g., Parry & Small (2009); Hahn et al. (2023); Almagro et al. (2024); Kreindler et al. (2023, 2024); Tsivanidis (2023)

- *This paper*: (1) Provides evidence on senior subsidies and informs better design.
  (2) Studies a highly congested transit system in a rapidly aging society.

Discrete-Choice / BLP Identification. e.g., Berry (1994); BLP (1995); Verboven (1996); Waldfogel (2003); Fan (2013); Fu & Gregory (2019); Einav et al. (2020)

- *This paper*: (1) Uses RD to identify nesting structure and parameters of HNL model.
  (2) Identifies BLP-type model using exogenous policy variation.

Appendix

Data: KT's Origin-Destination Level Mobility Data

Back to Data

- Measure individuals' transportation use
  - Based on cellphone signal movements between cellular base stations
  - Hourly number of trips made by subways, buses, and cars (including both personal cars and taxis) for each OD
  - Provided by KT, the second-largest mobile telecom carrier in Korea with a 30.1% market share as of 2022
  - Covers mobility of Great Seoul residents during June to August, 2023
- Link individuals' age (in year) to the each cell phone trip
  - Using enrollees' resident registration number
  - Forbidden from using individual-level data due to privacy regulations
  - The data was aggregated at the trip's OD, day, hour, and transportation mode and an enrollees' age and the residential area
  - Combined with population estimates, calculate the number of transportation use per person

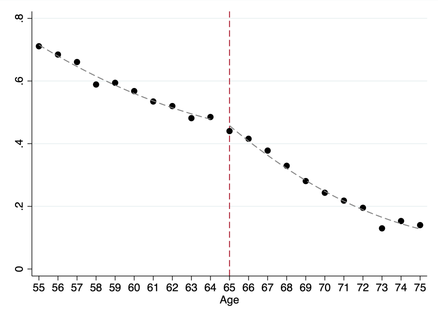
Other Data Details

- Stated Preference Survey
  - Measure individuals' WTP for congestion
  - Choose a trip plan and transportation mode under different hypothetical levels of congestion for each mode
  - Used only for welfare calculations (not for reduced form analyses)
- Korean National Health and Nutrition Survey (KNHANES)
  - Several measures of time spent for walk and exercise and physical and mental health
  - Restrict the sample to those reside in Seoul, Gyeonggi, and Incheon during 2019 – 2023

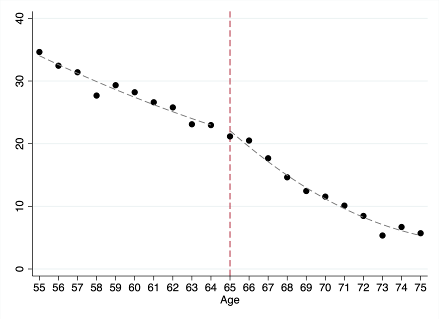
Age Profiles of Labor Supply

Back to RDD

Pr(employed)



Working hours

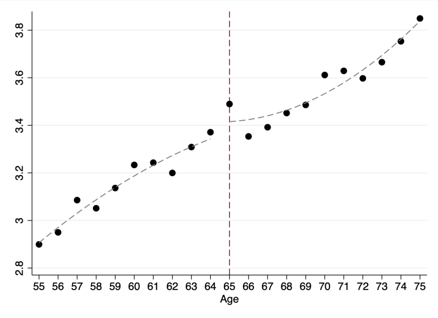


Data source: KLIPS, 2010 – 2017
Notes: We restrict the sample to those aged 55 and 75.

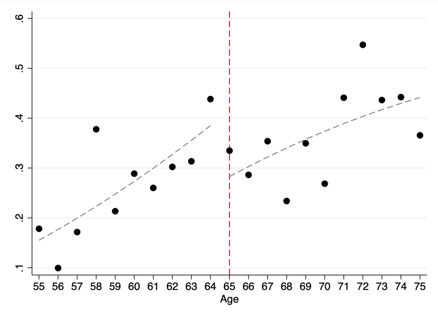
Age Profiles of Healthcare Utilization

Back to RDD

Log(Number of Outpatient Visits)



Log(Number of Hospital Admissions)



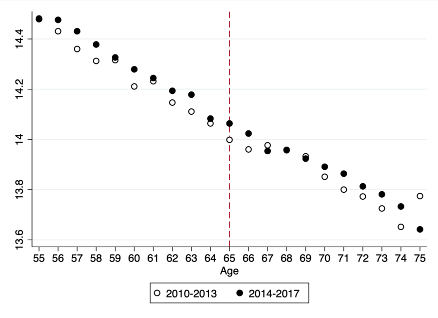
Data source: KHP, 2010 – 2017

Notes: We restrict the sample to those aged 55 and 75.

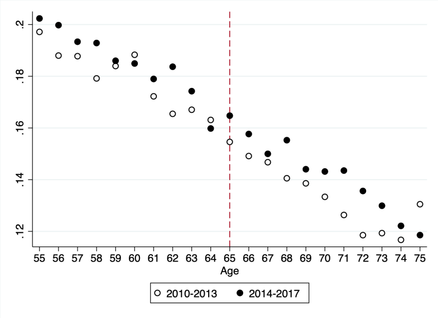
Age Profiles of Consumption Expenditure

Back to RDD

Total Expenditure



Share of Leisure Spending



Data source: KHIES, 2010 – 2017
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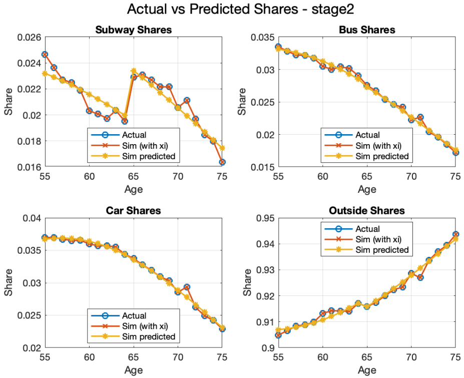
Demand for Transportation

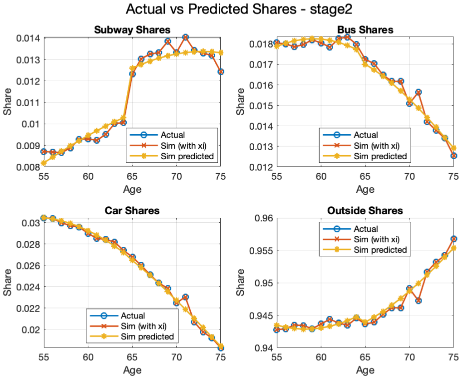
Model Fit - High SES, Peak Hours



Back to Model Fit

Demand for Transportation

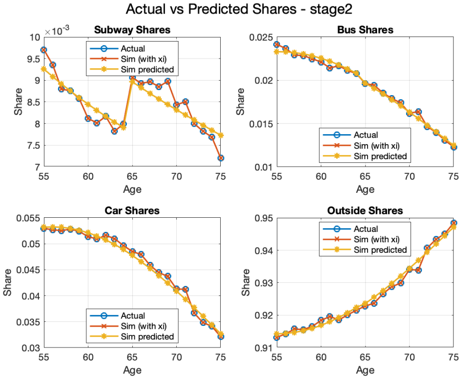
Model Fit - High SES, Off-peak Hours



Back to Model Fit

Demand for Transportation

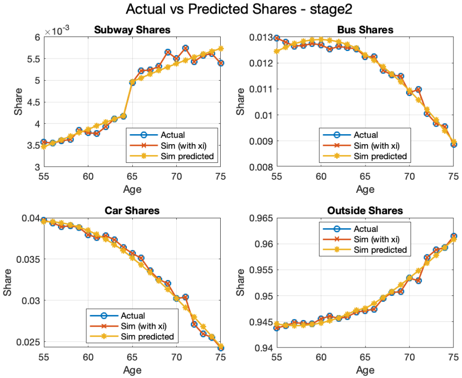
Model Fit - Low SES, Peak Hours



Back to Model Fit

Demand for Transportation

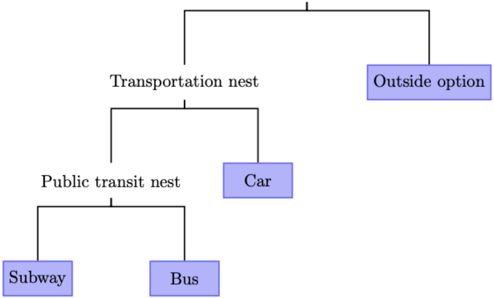
Model Fit - Low SES, Off-peak Hours



Back to Model Fit

Identified Hierarchical Nest Structure

Back to Model



The nesting structure is identified from the ordering of discontinuities in log demand across modes at age 65.

Utilities

Back to Model

- Individual i's utility from using a mode $m \neq 0$ at hour h:

$$u_{imh} = -\alpha^{dt} p_{ma} + \beta_m^{dt} c_m^t + \gamma_m^{dt}(a) + \tilde{\xi}_{ma}^{dt} + e_{imh}$$

  - p_{ma}: price of mode m for individual i at age $a \equiv a(i)$

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- Utility from outside option: $u_{i0h} = e_{i0h}$

Simulating Counterfactual Policies

Back to Model

a policy changes prices and equilibrium congestion

- A policy is (almost) characterized by $p = (p_{ma})$ for each mode m and age a

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- Practically:
  1. Start with status quo congestion/shares $s^0 = s^{SQ}$
  2. Compute mode shares $s^1 = sh(p, s^0)$ using estimated model
  3. Iterate until convergence: $s^* = sh(p, s^*)$

Extrapolation of Mean Utilities to Below 55

Back to Model

- KT mobility data covers individuals aged 55+
- We extrapolate mode shares for under-55 using the 2021 Household Travel Survey (HTS)
- To adjust for differences between HTS (self-reported) and KT (observed), we:
  1. Compute mode shares by age from both datasets
  2. Compare them for age 55+, where both are available
  3. Apply scaling factors to HTS shares under age 55
- Result: Smooth transition in mode shares at age 55

Identification and Estimation: Detailed Intuition

Back to Identification

Ignoring $\gamma_m(a)$, three-level nested logit implies:

$$\tilde{\xi}_{ma} = \ln(sh_{ma}/sh_{0a}) - \alpha p_{ma} - 1(m \in g_1)(1-\lambda_1)\ln(sh_{ma/g_1}) - 1(m \in g_2)(1-\lambda_2)\ln(sh_{ma/g_2}), \quad m \neq 0$$

$$\begin{aligned}
\Delta\tilde{\xi}_{ca}(\lambda_2) &= \Delta\ln(sh_{ca}/sh_{0a}) - (1-\lambda_2)\Delta\ln(sh_{ca/g_2})) \\
\Delta\tilde{\xi}_{ba}(\lambda_1,\lambda_2) &= \Delta\ln(sh_{ba}/sh_{0a}) - (1-\lambda_1)\Delta\ln(sh_{ba/g_1}) - (1-\lambda_2)\Delta\ln(sh_{ba/g_2}) \\
\Delta\tilde{\xi}_{sa}(\alpha,\lambda_1,\lambda_2) &= \Delta\ln(sh_{sa}/sh_{0a}) + \alpha\Delta p_{sa} - (1-\lambda_1)\Delta\ln(sh_{sa/g_1}) - (1-\lambda_2)\Delta\ln(sh_{sa/g_2})
\end{aligned}$$

- Proportion of increased subway shares drawn from car rather than outside option as a result of subsidy policy identifies the strength of upper nest λ_2
  - $\hat{E}[\Delta\tilde{\xi}_{ca}(\lambda_2)\Delta p_{sa}] = 0 \Leftrightarrow \Delta\ln\left(\frac{sh_{c,65}}{sh_{0,65}}\right) = (1-\lambda_2)\Delta\ln\left(\frac{sh_{c,65}}{1-sh_{0,65}}\right) = 0$
- Proportion of increased subway shares drawn from bus rather than car identifies the strength of lower nest λ_1
- How much subway share increases identifies α

RUM Estimates

Back to Model

Table 6: Parameter Estimates of the Random Utility Model

Parameters	Peak			Off-peak		
	All	High-SES	Low-SES	All	High-SES	Low-SES
λ_t	1.000	1.000	0.943	1.000	0.906	1.000
	[0.208, 1]	[0.802, 1]	[0.375, 1]	[0.529, 1]	[0.451, 1]	[0.760, 1]
λ_b	0.645	0.842	0.428	0.683	0.650	0.830
	[0.197, 1]	[0.493, 1]	[0.331, 1]	[0.192, 1]	[0.261, 1]	[0.332, 1]
$1000 \cdot \alpha$	0.096	0.119	0.052	0.102	0.100	0.095
	[0.025, 0.106]	[0.089, 0.122]	[0.034, 0.067]	[-0.145, 0.408]	[0.058, 0.104]	[0.039, 0.095]
γ_{s0}	-6.131	-4.979	-4.967	-8.091	-8.632	-7.856
	[-8.301, -3.958]	[-7.049, -3.378]	[-6.214, -2.714]	[-11.947, -4.415]	[-11.027, -5.203]	[-9.453, -6.162]
γ_{b0}	-6.897	-6.718	-7.237	-7.640	-7.927	-9.504
	[-8.592, -5.382]	[-7.553, -5.849]	[-8.028, -5.613]	[-8.956, -6.312]	[-8.839, -5.639]	[-10.466, -7.395]
γ_{c0}	-6.295	-7.780	-7.235	-7.443	-6.661	-6.919
	[-7.707, -4.599]	[-8.271, -6.883]	[-7.929, -5.063]	[-7.954, -6.638]	[-7.036, -5.218]	[-7.598, -6.099]
γ_{s1}	0.102	0.070	0.053	0.108	0.137	0.077
	[0.032, 0.168]	[0.013, 0.129]	[-0.016, 0.094]	[0.030, 0.191]	[0.047, 0.191]	[0.033, 0.135]
γ_{b1}	0.141	0.139	0.142	0.128	0.145	0.183
	[0.100, 0.194]	[0.114, 0.169]	[0.090, 0.167]	[0.090, 0.169]	[0.086, 0.170]	[0.140, 0.208]
γ_{c1}	0.127	0.169	0.160	0.154	0.127	0.142
	[0.077, 0.171]	[0.145, 0.184]	[0.092, 0.180]	[0.130, 0.169]	[0.085, 0.139]	[0.117, 0.164]
γ_{s2}	-0.00096	-0.00074	-0.00059	-0.00075	-0.00100	-0.00050
	[-0.001474, -0.000392]	[-0.001197, -0.000265]	[-0.000898, -0.000056]	[-0.001264, -0.000278]	[-0.001331, -0.000318]	[-0.000996, -0.000164]
γ_{b2}	-0.00131	-0.00132	-0.00131	-0.00107	-0.00121	-0.00153
	[-0.001728, -0.000978]	[-0.001541, -0.001121]	[-0.001513, -0.000898]	[-0.001386, -0.000749]	[-0.001422, -0.000782]	[-0.001709, -0.001185]
γ_{c2}	-0.00118	-0.00149	-0.00143	-0.00138	-0.00117	-0.00128
	[-0.001519, -0.000790]	[-0.001608, -0.001305]	[-0.001583, -0.000905]	[-0.001497, -0.001165]	[-0.001234, -0.000803]	[-0.001436, -0.001067]

Notes: λ_t and λ_b represents the nesting parameters for the top nest—consisting of bus, subway, and car—and the bottom nest—consisting of subway and bus—respectively. Correlation within nests equals zero when both parameters equal one. When $\lambda_b < \lambda_t$, alternatives in the bottom nest exhibit additional correlation beyond that captured by the top-level nest. Columns represent socioeconomic status groups, with High-SES and Low-SES representing those living in districts (gu) with above- and below-median housing prices, respectively. Subscripts $m = s, b, c$ represent subway, bus, and car, respectively. The covariates in age is specified as $\gamma_m(a) = \gamma_{0m} + \gamma_{1m} \cdot a + \gamma_{2m} \cdot a^2$. α is multiplied to prices in Korean won. The parameters are estimated with the KT mobility data. 95% confidence intervals in brackets are computed using wild bootstrap with Rademacher weights.

Optimal Policy: Other Versions

Back to Optimal Policy

Varying weights on high-SES elderly vs. low-SES elderly