The 25th Behavior Modeling Summer School

Joint Travel-Choice Modelling for Reducing Peak-Hour Crowding in Toyosu

IITB Team

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Introduction

Urban Challenge

Peak-hour congestion is a major issue in metropolitan areas like Tokyo, leading to overcrowded rail/metro systems and congested traffic in central areas.

Interconnected Travel Decisions

Travellers make multiple interrelated choices:

Vehicle ownership	Location choice	Mode choice	Departure time
Do I own a vehicle?	*Where do I go?*	*How do I travel?*	*When do I depart?*

These decisions may be influenced by **unobserved individual preferences**, creating dependency across choice dimensions.

Research Gap

Conventional models often estimate these decisions independently, potentially overlooking the interdependencies between them.

Our Approach

We develop an **integrated joint travel-choice model** using **error components** to capture unobserved dependency across individual discrete choice models.

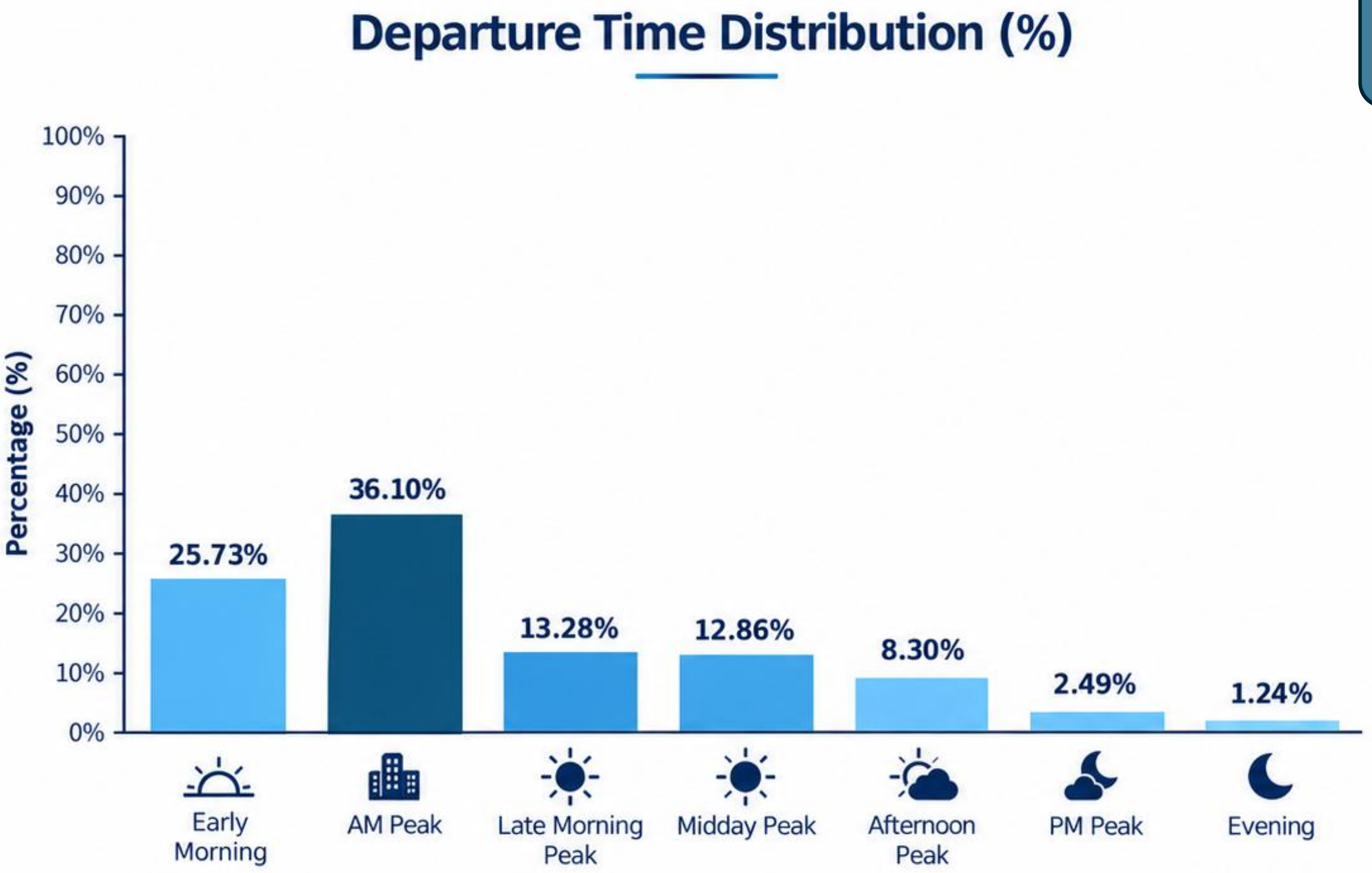
Policy Application

We apply the framework to Toyosu, Tokyo, to evaluate **land-use decentralization policies** and their effects on location, mode, and departure-time choices, with the aim of reducing peak-hour traffic and crowding.

Research Objective

To investigate how changes in the spatial distribution of land use can influence interconnected travel choices and **reduce peak-period concentration in the central area.**

Data | Descriptive Statistics | Departure Time Choice



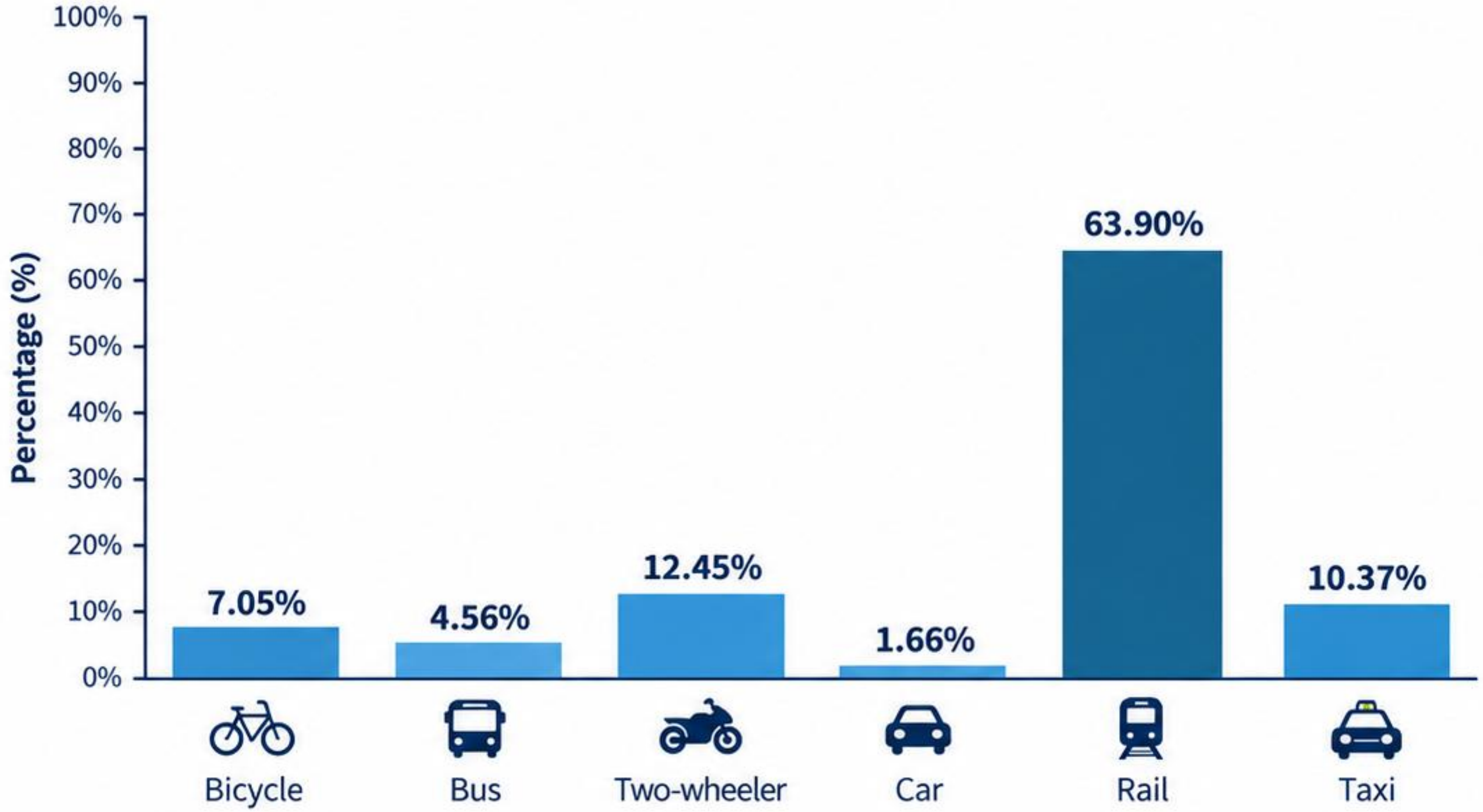
Analysing 241 People's Work Trip Data

Departure Period	Percentage
Early Morning	25.73%
AM Peak	36.10%
Late Morning Peak	13.28%
Midday Peak	12.86%
Afternoon Peak	8.30%
PM Peak	2.49%
Evening	1.24%

Key Insight

Most departures are concentrated in the morning; Early Morning + AM Peak account for 61.83% of trips.

Mode Choice Distribution (%)



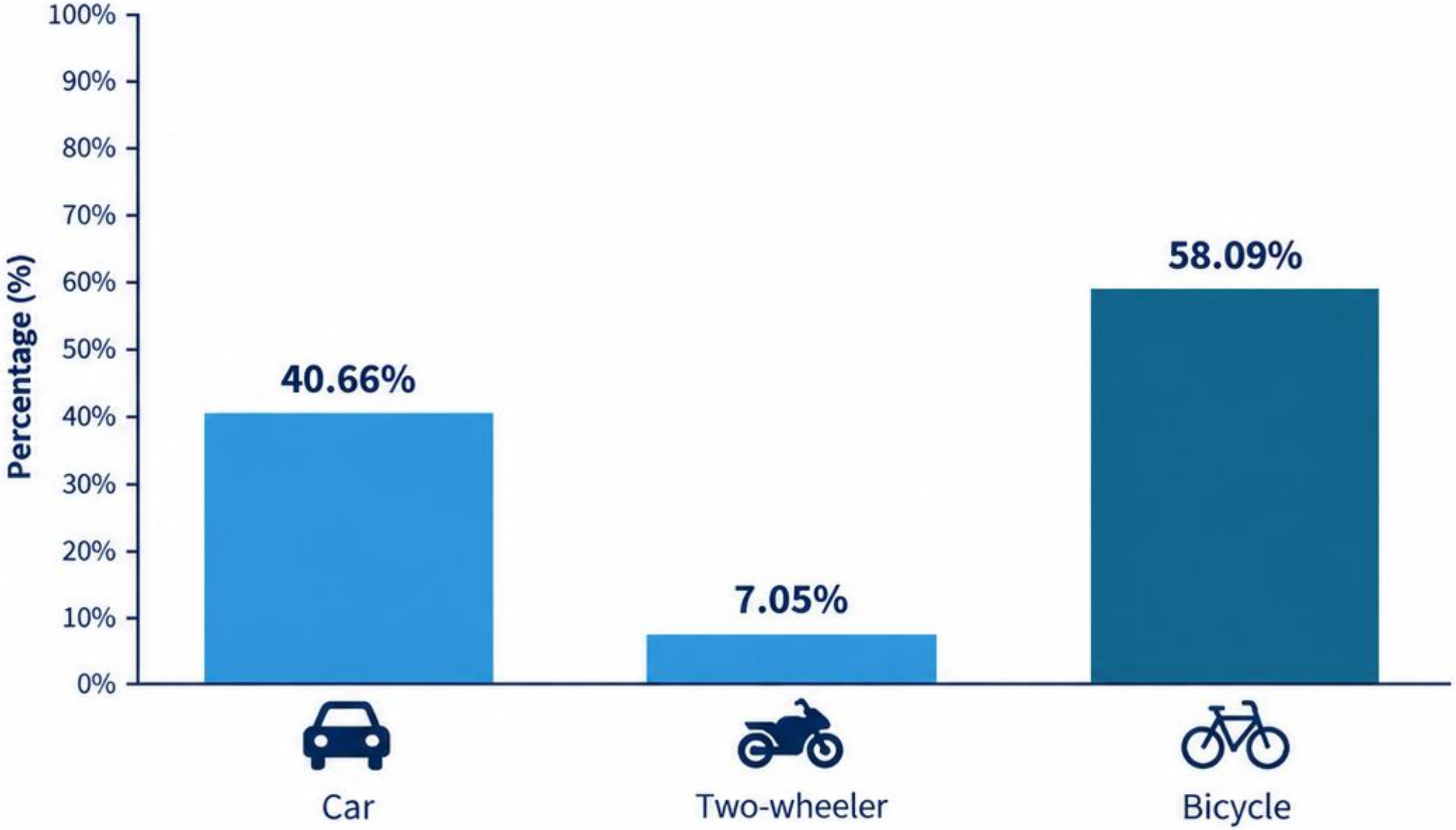
Mode	Percentage
Bicycle	7.05%
Bus	4.56%
Two-wheeler	12.45%
Car	1.66%
Rail	**63.90%**
Taxi	10.37%

Key Insight

Rail dominates the sample, while car use is very limited.

Data | Descriptive Statistics | Vehicle Ownership

Vehicle Ownership (%)



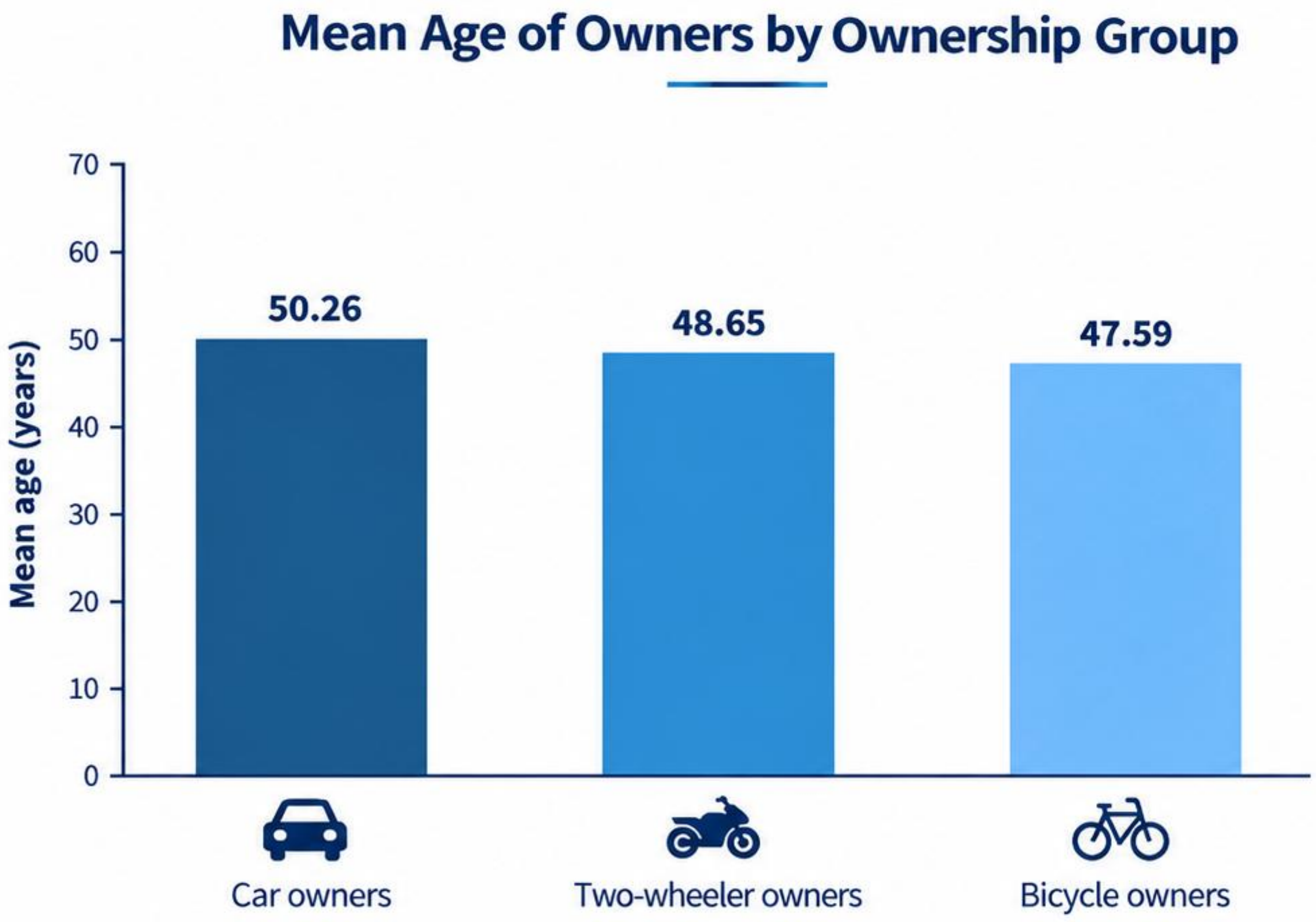
Vehicle type	Percentage
Car	40.66%
Two-wheeler	7.05%
Bicycle	58.09%

Percentages do not sum to 100% because respondents may own more than one vehicle type.

Key Insight

Bicycle ownership is the most common, while two-wheeler ownership is relatively rare.

Data | Descriptive Statistics | Average of Vehicle Owners



Ownership group	Mean age (years)	Median age (years)
Car owners	50.26	51
Two-wheeler owners	48.65	45
Bicycle owners	47.59	47

Key Insight

Car owners are the oldest on average among the three ownership groups.

Data | Descriptive Statistics | Age and Income

Age
Summary Statistics (Years)

Statistic	Age (Years)
Mean	46.76
Std. dev.	12.11
Median	46
Minimum	19
Maximum	80

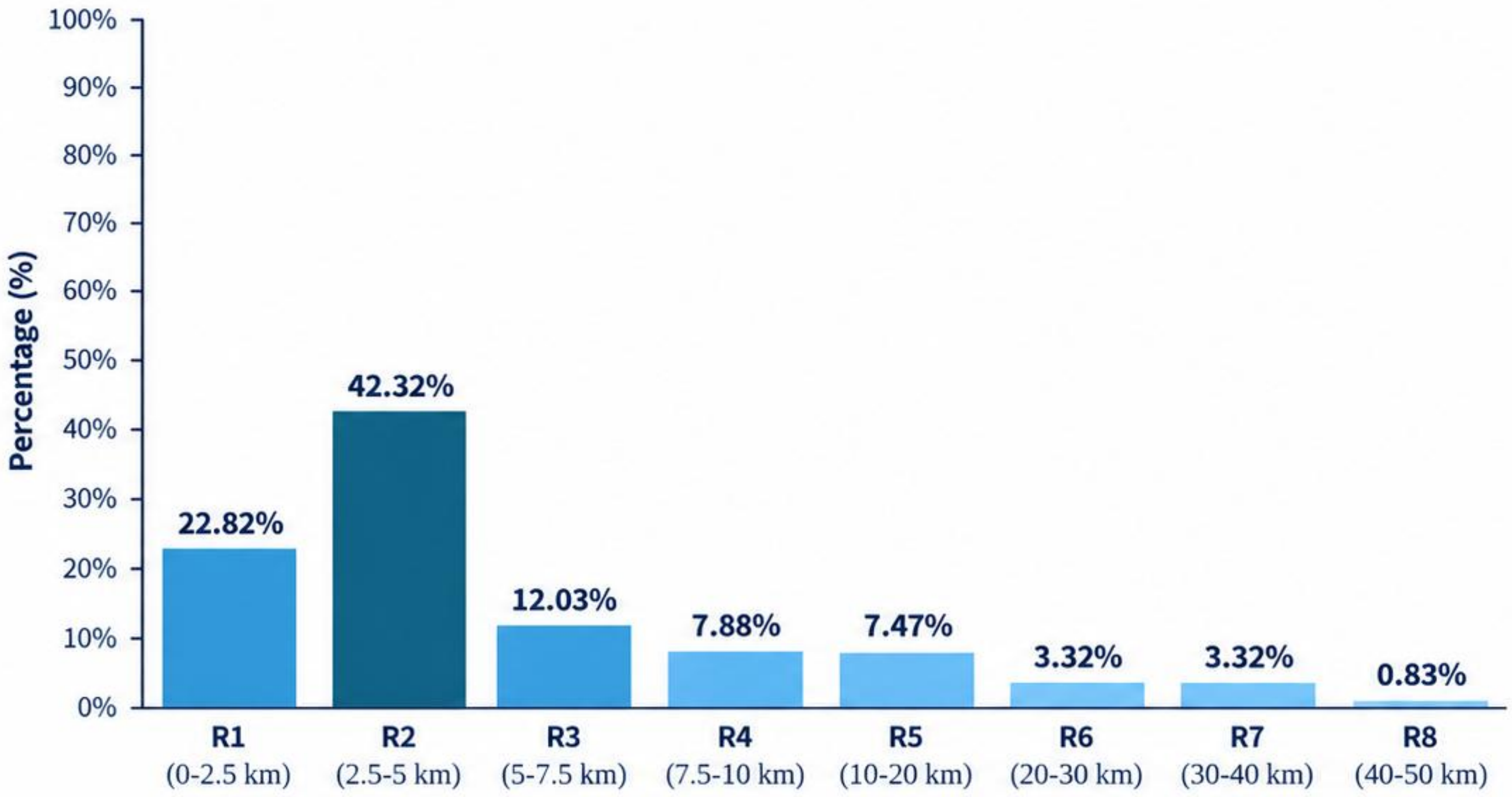
Income
Summary Statistics (Million Yen per Year)

Statistic	Income (Million Yen per Year)
Mean	8.73
Std. dev.	4.66
Median	8.21
Minimum	0.81
Maximum	19.77

Key Insight

The sample is middle-aged on average and shows substantial variation in both age and income.

Location Choice by Ring (%)



Ring	Distance range	Percentage
R1	0 - 2.5 km	22.82%
R2	2.5 - 5 km	**42.32%**
R3	5 - 7.5 km	12.03%
R4	7.5 - 10 km	7.88%
R5	10 - 20 km	7.47%
R6	20 - 30 km	3.32%
R7	30 - 40 km	3.32%
R8	40 - 50 km	0.83%

Key Insight

Work destinations are highly concentrated near the centre; Rings 1-2 account for 65.15% and Rings 1-4 account for 85.06% of observations.

Integrated Travel-Choice Framework

$$U_{ij}^{CO} = V_{ij}^{CO} + \eta_{i,1} + +\varepsilon_{ij}^{CO}$$

Car Ownership, Binary Logit Model

$$U_{ik}^{TWO} = V_{ik}^{TWO} + \eta_{i,1} + \varepsilon_{ik}^{TWO}$$

Two-wheeler ownership, Binary Logit Model

$$U_{il}^{CyO} = V_{il}^{CyO} + \eta_{i,1} + \varepsilon_{il}^{CyO}$$

Cycle Ownership, Binary Logit Model

$$U_{im}^{Mode} = V_{im}^{Mode} + \eta_{i,1} + \varepsilon_{im}^{Mode}$$

Mode choice, MNL, 6 Alternative

$$U_{in}^{Loc} = V_{in}^{Loc} + \eta_{i,1} + \varepsilon_{in}^{Loc}$$

Location Choice, MNL, 8 Alternative

$$U_{io}^{DT} = V_{io}^{DT} + \eta_{i,1} + \varepsilon_{io}^{DT}$$

Departure time choice, MNL, 7 Alternatives

$$L_i = \frac{1}{R}\sum_{r=1}^{R}\prod_{t} P_{it|r}$$

Likelihood Function given r, individual i , t choice occasion

Walker, J. L. (2001). *Extended discrete choice models: integrated framework, flexible error structures, and latent variables* (Doctoral dissertation, Massachusetts Institute of Technology).

$$LL(\theta) = \sum_{i} \log(L_i)$$

Independent Model Results

Toyosu 2021 Work-Trip Sample
N = 241

Significant if |t| > 1

Estimated Before the Joint Model

Purpose of independent models

The independent binary/MNL models provide the behavioural baseline for each choice dimension before introducing the common unobserved term in the joint framework.

1 Vehicle ownership

Separate binary logit models for car, two-wheeler, and bicycle ownership capture distinct asset-ownership profiles.

2 Mode choice

MNL model evaluates rail, bicycle, bus, two-wheeler, car, and taxi. Rail is the reference alternative.

3 Departure time choice

MNL model compares non-AM-peak alternatives relative to AM Peak, emphasizing peak spreading behaviour.

4 Location choice

MNL model explains ring-based work-location choice using land-use variables and spatial heterogeneity.

5 Behavioural synthesis

Independent findings motivate the integrated specification: utility = systematic utility + common $\eta_{i,1}$ + choice-specific error.

6 Policy linkage

Model outputs support policy scenarios related to centralization, rail dependence, and peak-period crowding.

Key message The independent models show rail dominance, AM-peak concentration, centralized work destinations, and distinct ownership patterns by age and income.

Binary Logit Models: Vehicle Ownership

Outcome: owns vehicle type = 1 | **t-stat threshold: |t| > 1**

Estimated coefficients

Model	Parameter	Estimate	t-value	Behavioural direction
Car	ASC	-2.884	-4.508	
Car	Age	0.0407	3.397	Positive
Car	Income	0.0650	2.193	Positive
Bicycle	ASC	-0.612	-1.098	
Bicycle	Age	0.0114	1.034	Positive
Bicycle	Income	0.0470	1.624	Positive
Two-wheeler	ASC	-2.846	-2.673	
Two-wheeler	Income	-0.0603	-1.037	Negative

Behavioural interpretation

Car ownership

Age and income both increase the probability of car ownership. This indicates stronger car ownership among older and higher-income respondents.

Bicycle ownership

Age and income have positive effects, but the age effect is modest. Bicycle ownership is not limited to younger or lower-income respondents.

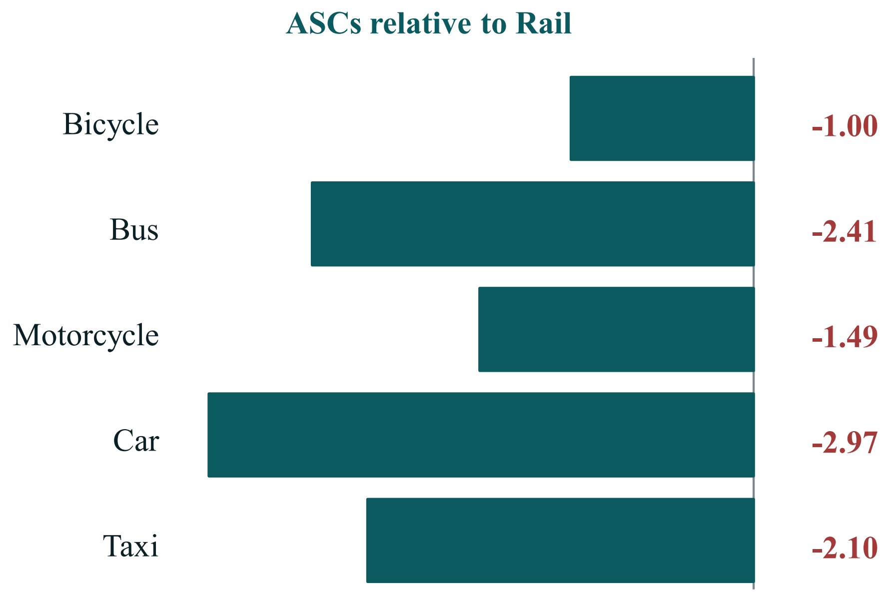
Two-wheeler ownership

Income has a negative effect, suggesting a different socioeconomic profile compared with car and bicycle ownership.

Ownership pattern: Car = age (+), income (+) | Bicycle = age (+), income (+) | Two-wheeler = income (−)

MNL Model: Mode Choice

Reference Alternative: Rail | **Generic Travel-Time Coefficient** | **T-Stat Threshold: |t| > 1**



Parameter	Estimate	t-value	Interpretation
ASC Bicycle	-0.996	-4.491	
ASC Bus	-2.407	-5.585	
ASC Motorcycle	-1.494	-6.254	
ASC Car	-2.970	-7.351	
ASC Taxi	-2.105	-7.278	
Travel time	-8.37e-05	-1.895	**Longer time reduces utility**
Female × Taxi	1.158	3.090	**Stronger taxi preference**

Slide use: connect this to the joint model by saying that mode choice is influenced by both observed travel attributes and unobserved individual preferences.

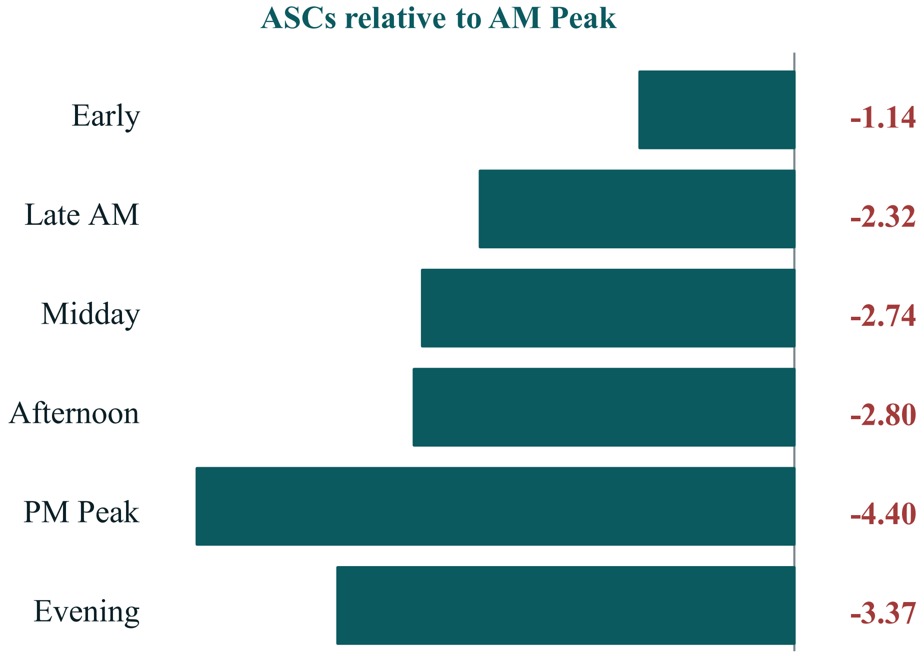
Key behavioural message

Rail is the dominant baseline mode in the work-trip sample. Travellers are sensitive to travel time, and female respondents show a stronger preference for taxi.

MNL Model: Departure Time Choice

Reference alternative: AM Peak

t-stat threshold: |t| > 1



Effect	Estimate	t-value	Behavioural meaning
Age × Early Morning	0.0175	1.267	Older → early departure
Age × Late Morning	0.0283	1.643	Older → late morning
Age × Midday	0.0363	2.081	Strongest age effect
Age × Afternoon	0.0287	1.391	Older → afternoon
Income × PM Peak	0.1657	1.909	Higher income → PM Peak

Main finding: AM Peak has the strongest baseline preference, while age systematically shifts some work trips away from the conventional AM peak.

Age-related peak spreading

Positive age effects indicate that older respondents are more likely to choose non-AM-peak departure periods, especially midday.

Income effect

Higher income increases the propensity for PM-peak departure relative to AM Peak.

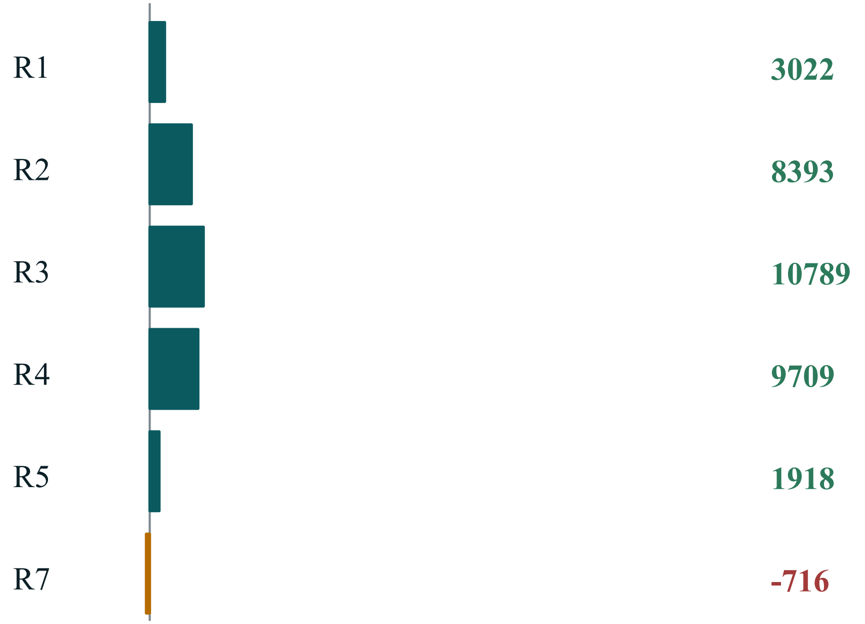
MNL Model: Location Choice

Reference alternative: Ring 8

Work-location choice across 8 rings

t-stat threshold: |t| > 1

Railway land-use effect by ring



Parameter	Estimate	t-value	Meaning
LU010 × Ring 1	3021.7	4.992	Positive railway effect
LU010 × Ring 2	8392.9	9.053	Strong positive
LU010 × Ring 3	10789.0	10.106	Strongest effect
LU010 × Ring 4	9709.0	9.870	Very strong positive
LU010 × Ring 5	1917.5	3.511	Positive but weaker
LU010 × Ring 7	-715.8	-2.643	Negative outer-ring effect
LU006+016	767.4	3.521	Industrial–waterfront attraction

Interpretation caution: coefficient magnitudes should be interpreted with the scale of land-use variables.

Spatial heterogeneity
Railway land use does not affect all rings equally. Its attraction is strongest in Rings 2–4 and weakens toward outer rings.

Policy relevance
The location model supports policy scenarios that redistribute employment-related activities and evaluate crowding impacts.

Joint Model Results: Updated Estimated Parameters and Common Unobserved Factor

Toyosu 2021 Work-Trip Sample | Joint model with common unobserved factor | Significance assessed using t-values

Choice dimension	Parameter	Estimate	t-value
Car ownership	car_ASC_car	-1.892	-9516.553
	car_beta_age	0.034	8.632
Two-wheeler ownership	tw_ASC	-0.652	-232.687
	tw_beta_age	-0.027	-1.666
	tw_beta_income	-0.243	-2.033
Cycle ownership	cy_ASC_Cycleown	-0.459	-1093.245
	cy_beta_age	0.014	2.534
	cy_beta_income	0.023	0.829
Departure-time choice	DT_ASC_EarlyMorning	0.053	8.426
	DT_ASC_LateMorningPeak	-0.624	-217.606
	DT_ASC_MiddayPeak	-0.876	-222.942
	DT_ASC_AfternoonPeak	-0.660	-375.511
	DT_ASC_PMPeak	-2.080	-238.179
	DT_ASC_Evening	-1.588	-5.523
	DT_beta_age_EarlyMorning	-0.006	-1.634
	DT_beta_age_LateMorningPeak	-0.005	-1.002
	DT_beta_age_MiddayPeak	0.007	1.759
	DT_beta_age_AfternoonPeak	-0.014	-2.491
Mode choice	mode_ASC_Bicycle	-1.796	-6.359
	mode_ASC_Bus	-1.099	-4.022
	mode_ASC_Motorcycle	-1.719	-7.065
	mode_ASC_Car	-3.732	-65.786
	mode_ASC_Taxi	-1.947	-12.642
	mode_beta_time	-0.000	-3.500
	mode_beta_female_Taxi	0.439	4.666
Location choice	loc_ASC_1	1.140	7.619
	loc_ASC_2	1.600	12.600
	loc_ASC_3	0.928	5.736
	loc_ASC_4	0.562	2.996
	loc_ASC_5	0.529	2.780
	loc_ASC_6	0.207	0.952
	loc_ASC_7	0.208	0.957
	loc_beta_LU010_R2	0.022	6.784
	loc_beta_LU010_R4	0.191	45.172
	loc_beta_LU010_R5	-0.059	12.325
	loc_beta_LU010_R7	-0.044	-9.228
	loc_beta_LU006_016	0.117	320.306
Common unobserved factor	**log_sd_eta (common unobserved factor across all choices)**	**-2.182**	**-1068.367**

Key interpretation

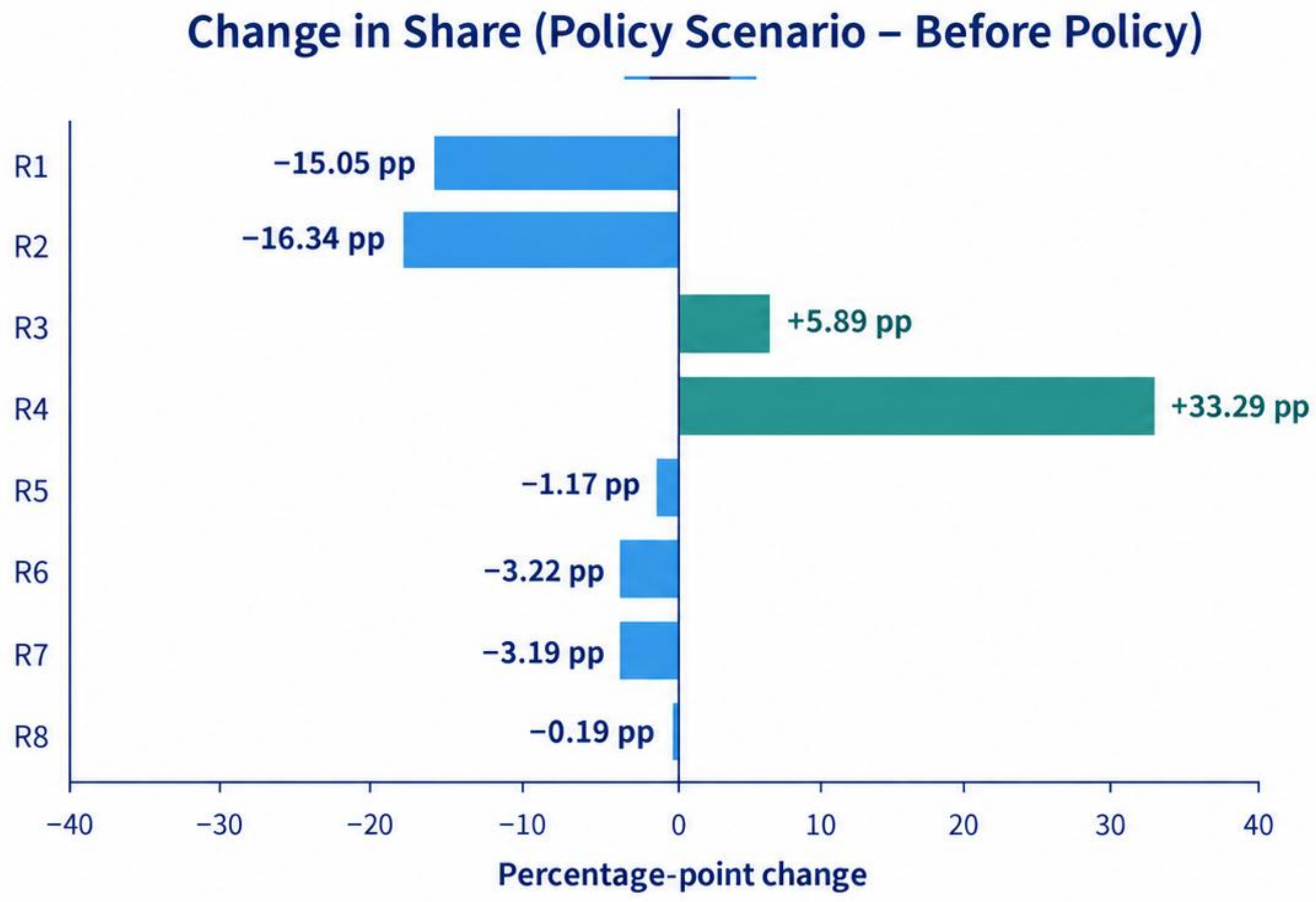
1. The joint model estimates ownership, departure-time, mode, and location choices simultaneously in one integrated framework.

2. The common unobserved factor across all choices is estimated through the parameter log_sd_eta, which links the different choice utilities.

3. The estimated common unobserved factor is statistically very strong (log_sd_eta = -2.182, t-value = -1068.367), indicating that shared unobserved influences matter across the choice dimensions.

Main message: The joint model estimates a common unobserved factor across all choice dimensions while also identifying important observed effects of age, income, travel time, gender, and land use.

Policy Simulation



N = 241
work-trip observations

Ring	Change (pp)
R1	−15.05
R2	−16.34
R3	+5.89
R4	+33.29
R5	−1.17
R6	−3.22
R7	−3.19
R8	−0.19

Largest increase: R4 (+33.29 pp)
Largest decline: R2 (−16.34 pp)
Second-largest decline: R1 (−15.05 pp)

Key Insight

The policy mainly redistributes location choice: from the inner rings toward Ring 4, indicating a strong decentralization effect.