Why did highways cause suburbanization? The role of highway congestion

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概要

- 目的：郊外化のメカニズムの解明
  - 理論

    通勤における混雑が労働者の通勤に与える影響の分析
  - 検証方法

    1950年から1990年までのアメリカ都市圏のデータを使用

    部分識別による検証
  - 結果

    提案モデル：アメリカ都市圏のデータから支持される

    既存モデル：中心都市の人口が多い都市のデータからは支持されない

Introduction

- 混雑
  - アメリカ都市圏(101都市)における混雑

    Texas Transport Institute の混雑指標によると

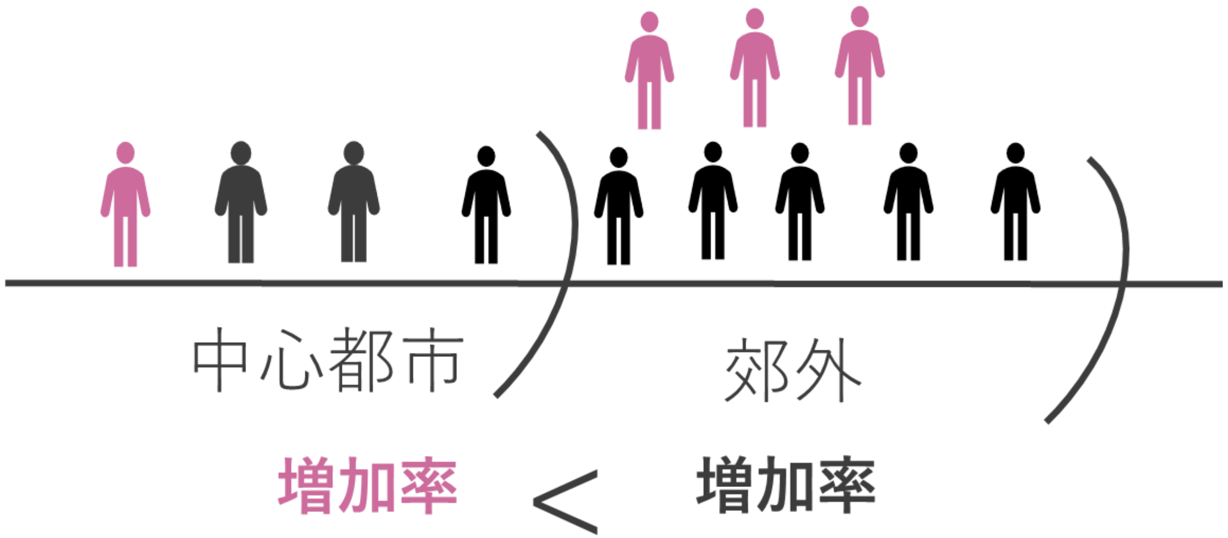
混雑費用	混雑による遅れ
1985年: 1人あたり$901	1985年: 1人あたり28時間
2010年: 1人あたり$1385	2010年: 1人あたり49時間

    Couture et al. (2018) によると

    混雑による死荷重 (2008年時点) 300億ドル
  - 混雑はアメリカ都市圏で大きな問題になっている

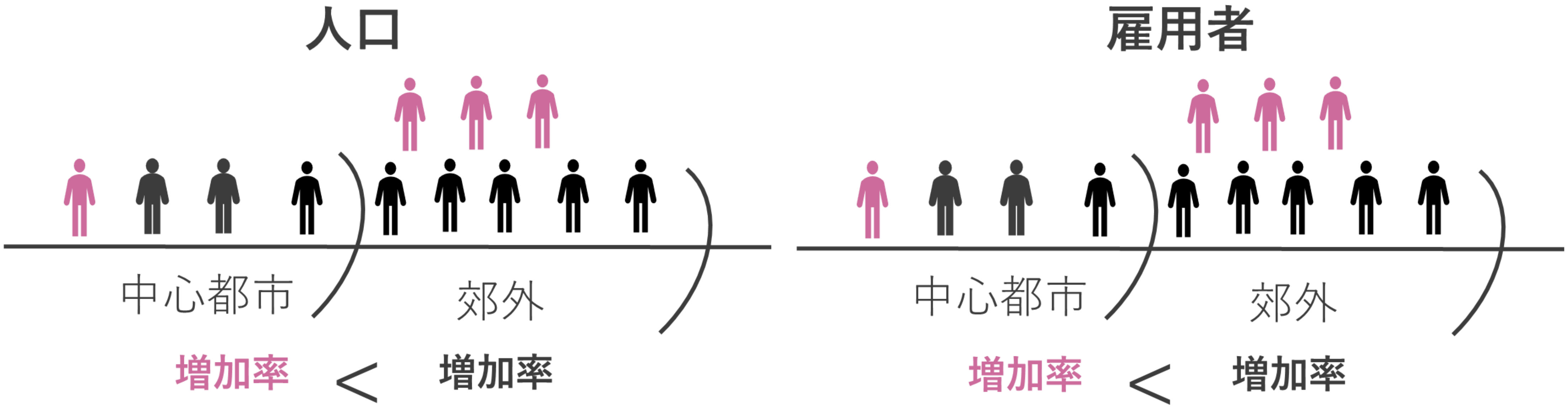
Introduction

- 居住地と職場の選択(通勤パターンの決定)
  - 混雑を考慮に入れたモデルの構築
  - 交通インフラの整備の影響と郊外化
- 郊外化 (Suburbanization)のメカニズムの解明



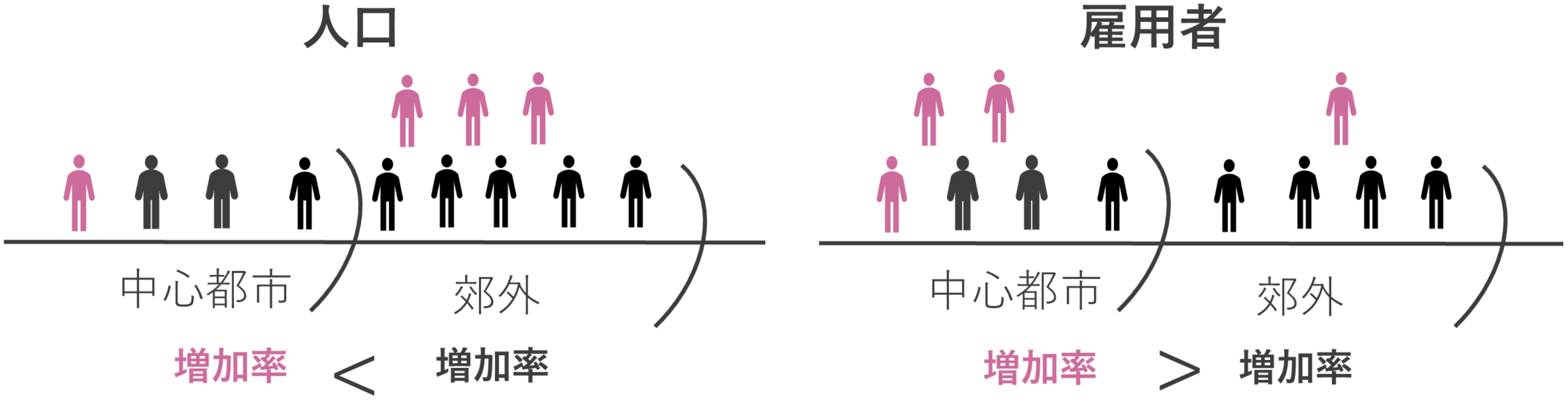
Introduction

- 郊外化 (Suburbanization) と交通インフラの整備
  - 実証研究
  - Baum-Snow (2007, 2010, 2019), Garcia-Lopez (2012), Garcia-Lopez et al. (2015)



Introduction

- 郊外化 (Suburbanization)
  - 理論研究 (Canonical Urban Model)
  - Lucas and Rossi-Hansberg (2002), Ahlfeldt et al. (2015)



Theoretical model

- 理論モデル
  - Canonical Urban model が基本

    Ahlfeldt et al. (2015) を参照
  - Heterogeneous commuting cost を取り入れる

    Baum-Snow (2007b) を参照
  - 高速道路上の混雑

Theoretical model

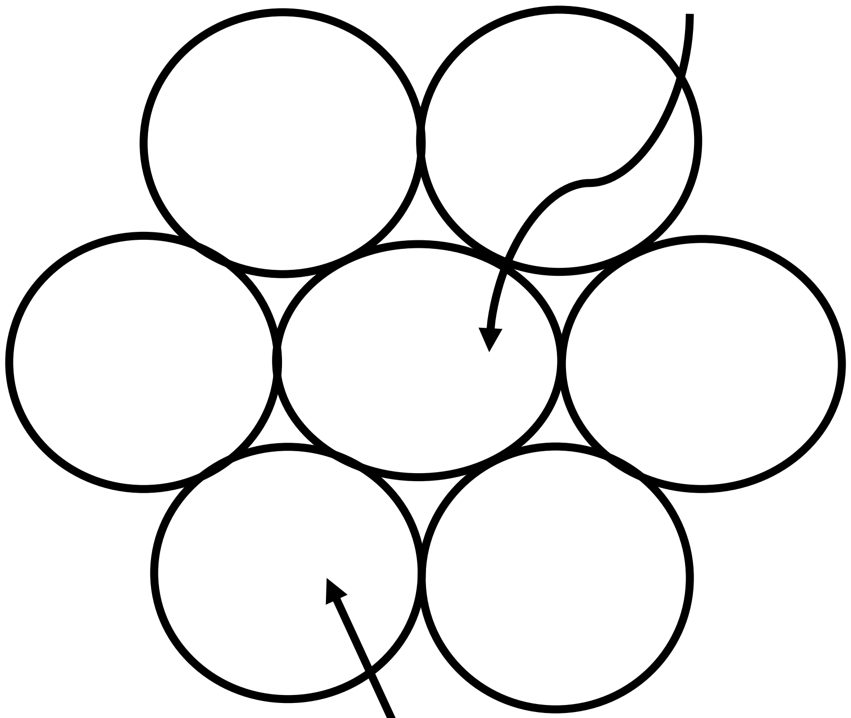
- 理論モデルの設定
  - 都市圏　→　中心都市 (c) と郊外 (s)

$$M = \{c, s_1, s_2, \dots, s_f\}$$

  - 消費者　→　居住地と職場を選択

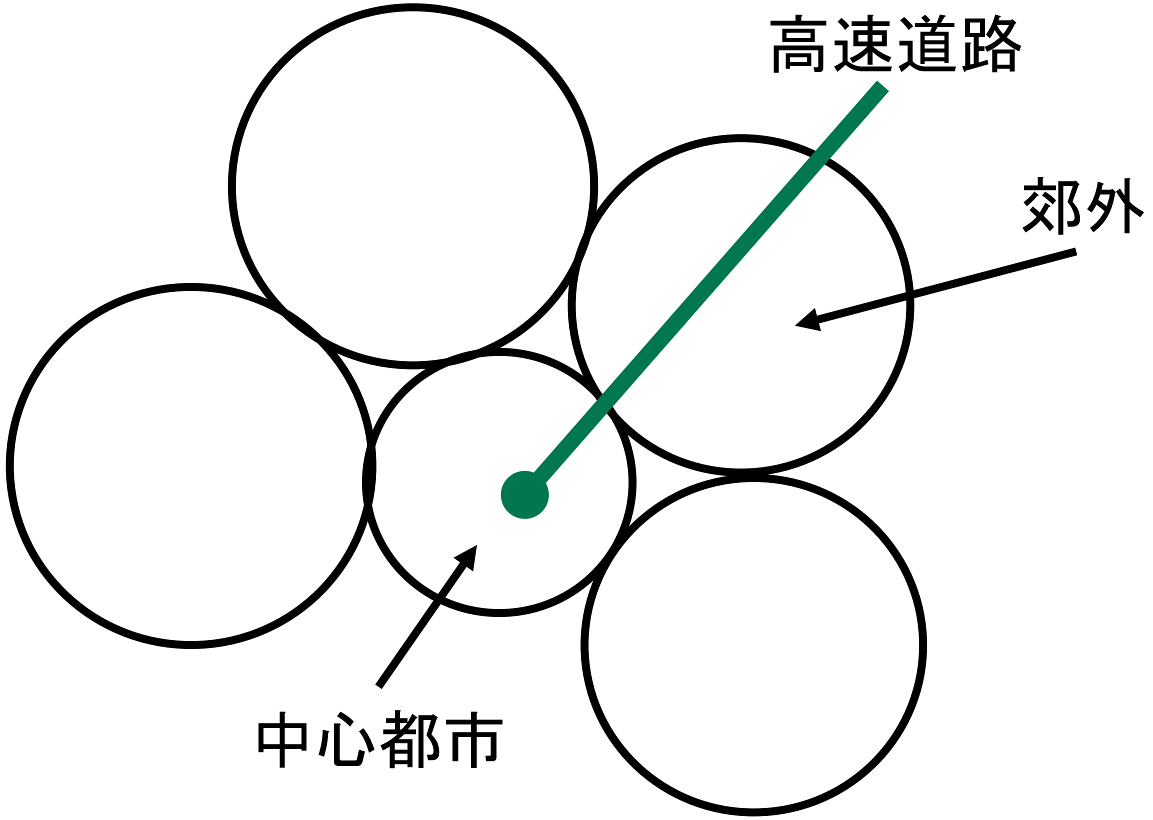
Open city model を採用

→　都市圏内の人口が変化する



Theoretical model

- 理論モデルの設定
  - Heterogeneous Commuting Cost
  - 高速道路と一般道



Theoretical model

理論モデル

労働者

効用関数

$$U_{ijo} = \frac{b_{ijo}}{k_{ij}} \left(\frac{c_{ij}}{\alpha}\right)^{\alpha} \left(\frac{h_{ij}}{1-\alpha}\right)^{1-\alpha}$$

i: 居住地、j: 職場 ($i, j \in M$)、o: 労働者

c_{ij}: 最終財の消費量、h_{ij}: 居住面積の広さ

k_{ij}: 通勤費用

b_{ijo}: 特異なアメニティショック (Fréchet分布に従う)

Theoretical model

理論モデル

労働者

特異なアメニティショック (Fréchet分布に従う)

$$G_{ij}(b) = e^{-B_i b^{-\epsilon}}$$

B_i: 居住地 i の平均的なアメニティ(きれいな景色、水など)、$B_i > 0$

ε : アメニティの分散、$\varepsilon > 1$

Theoretical model

- 理論モデル
  - 労働者の居住地と職場の選択
  - 労働者が i に住んで j で働く確率

$$\lambda_{ij}$$

居住地　職場

$$\lambda_{ij} = \frac{L_{ij}}{\bar{L}} = \frac{B_i \left(P_i^{\alpha} Q_i^{1-\alpha} k_{ij}\right)^{-\epsilon} w_j^{\epsilon}}{\sum_r^M \sum_t^M B_r \left(P_r^{\alpha} Q_r^{1-\alpha} k_{rt}\right)^{-\epsilon} w_t^{\epsilon}}$$

L_{ij}: i に住んで j で働く労働者数, $\bar{L}$: 都市圏内の総労働者数

P_r : 消費財の価格（輸送費を仮定しないので $P_r = P$）, Q_r: 地代

Theoretical model

- 理論モデル
  - 生産者

  生産関数

$$y_j = A_j L_j^{\beta} \left(H_j^F\right)^{1-\beta}$$

y_j: 最終財の生産量

A_j: 全要素生産性

L_j: 労働者数

H_j^F: 企業が使用する床面積

Theoretical model

- 理論モデル
  - 土地市場

土地市場均衡条件

労働者

企業

$$
\begin{aligned}
H_i =& H_i^W + H_i^F \\
=& (1-\alpha)\frac{\bar{w}_i}{Q_i}R_i + \left(\frac{(1-\beta)A_i}{Q_i}\right)^{1/\beta} L_i
\end{aligned}
$$

簡単化のため、地代は企業も労働者も共通とする

Theoretical model

- 理論モデル
  - 土地市場

土地の供給 (Saiz, 2010)

$$H_i = d_i K_i$$

$$d_i = dQ_i^{\mu},$$

d_i : 開発密度

K_i : 地理的な土地の広さ

d : 定数

μ : 土地の価格弾力性

Theoretical model

理論モデル

均衡

内生変数 $\{\boldsymbol{L}, \boldsymbol{R}, \boldsymbol{Q}, \boldsymbol{w}, \overline{\boldsymbol{w}}, \bar{L}\}$

外生変数、パラメータを所与として、均衡は以下の式から決定

1. 職場の選択確率

$$\lambda_j^L = \frac{\sum_i^M B_i \left(P_i^\alpha Q_i^{1-\alpha} k_{ij}\right)^{-\epsilon} w_j^\epsilon}{\sum_r^M \sum_t^M B_r \left(P_r^\alpha Q_r^{1-\alpha} k_{rt}\right)^{-\epsilon} w_t^\epsilon}$$

2. 居住地の選択確率

$$\lambda_i^R = \frac{\sum_j^M B_i \left(P_i^\alpha Q_i^{1-\alpha} k_{ij}\right)^{-\epsilon} w_j^\epsilon}{\sum_r^M \sum_t^M B_r \left(P_r^\alpha Q_r^{1-\alpha} k_{ij}\right)^{-\epsilon} w_t^\epsilon}$$

Theoretical model

理論モデル

均衡

3. 期待賃金

$$\bar{w}_i = \sum_j^M \frac{(w_j/k_{ij})^\epsilon}{\sum_t^M (w_t/k_{it})^\epsilon} w_j$$

4. ゼロ利潤条件

$$w_j = \beta A_j^\beta \left(\frac{1-\beta}{Q_j} \right)^{(1-\beta)/\beta}$$

5. 土地市場清算条件

$$H_i = (1-\alpha)\frac{\bar{w}_i}{Q_i} R_i + \left(\frac{(1-\beta)A_i}{Q_i} \right)^{1/\beta} L_i$$

6. 人口移動

$$\eta \left[\sum_r^M \sum_t^M B_r (P_r^\alpha Q_r^{1-\alpha} k_{rt})^{-\epsilon} w_t^\epsilon \right]^{1/\epsilon} = \bar{U}$$

Numerical Calculation

- 数値計算
  - 設定
  - 全要素生産性 A_i

$$A_j = a_j \Bigg(\overbrace{\underbrace{\sum_{j'}^{M} e^{-\rho_a \tau_{jj'}}}_{\text{空間的な減衰}} \left(\frac{L_{j'}}{K_{j'}}\right)}^{\text{集積の外部性}}\Bigg)^{\delta_a}$$

a_j: 外生的な要素、ρ_a: 空間的な減衰の割合

δ_a : 集積の外部性の重要度

Numerical Calculation

- 数値計算
  - 設定
  - 居住の外部性 B_i

$$B_i = b_i \Bigg[\overbrace{\sum_{i'}^{M} \underbrace{e^{-\rho_b \tau_{ii'}}}_{\text{空間的な減衰}} \left(\frac{R_{i'}}{K_{i'}} \right)}^{\text{居住の外部性}} \Bigg]^{\delta_b}$$

b_i: 外生的な要素、ρ_b: 空間的な減衰の割合

δ_b : 居住の外部性の重要度

Numerical Calculation

- 数値計算
  - 設定
  - 通勤費用 $$k_{ij} = e^{\kappa \tau_{ij}}$$

κ : 通勤における技術（通常の道 κ、高速道路 κ_h）

$\frac{\kappa}{2} = \kappa_h$（高速道路上の最高速度 65mph, 通常の道の最高速度 25～40mph）

τ_{ij}: ij 間の距離 ($\tau_{cc} < \tau_{s_i s_i} < \tau_{s_i c}$；　$\tau_{ii} = 2/3\sqrt{K_i/\pi}$)

Numerical calculation

- 1960年から2000年までのアメリカ都市圏における通勤パターン
  - Baum-Snow (2010) によると

中心都市	→	中心都市	:	45% (1960),	15% (2000)
中心都市	→	郊外	:	6% (1960),	7% (2000)
郊外	→	中心都市	:	16% (1960)	15% (2000)
郊外	→	郊外	:	34% (1960)	62% (2000)

→ 中心から郊外へ通勤する人は、少なく変化もないので、

今回は考慮に入れない

Numerical Calculation

- 数値計算
  - 設定
  - 通勤費用(郊外から中心へ):高速道路上の混雑

$$k_{s_f c} = e^{\left[\kappa_h + \underbrace{m(L_{s_f c} + L_{cc})}_{\text{高速道路の混雑}}\right]\tau_{s_f c}}$$

m: 混雑費用

Numerical Calculation

- 数値計算
  - 設定
  - 通勤費用(郊外内):高速道路上の混雑

$$k_{s_i s_i} = e^{\left\{\left[\kappa + \left(\kappa_k + \underbrace{m L_{s_i s_i}}_{\text{高速道路の混雑}}\right)\right]/2\right\}\tau_{s_i s_i}}$$

Numerical Calculation

- 数値計算
  - 設定
  - 通勤費用(中心都市内):高速道路上の混雑

$$k_{cc} = e^{\left\{\left[\overbrace{(sub-n_h)\kappa}^{\text{通常の道路}}+\overbrace{n_h(\kappa_h+\underbrace{m(L_{cc}+\sum_{i=1}^{\zeta} L_{s_i}c)}_{\text{高速道路の混雑}})}^{\text{高速道路}}\right]/sub\right\}\tau_{cc}}$$

Numerical Calculation

- 数値計算
  - 設定
  - パラメータ

parameters	value	
α consumption share	0.95	Lucas and Rossi-Hansberg (2002) Brinkman (2016)
β production technology	0.9	Lucas and Rossi-Hansberg (2002) Brinkman (2016)
μ Elasticity of floor space supply	1.75	Saiz (2010)
d Constant parameter (floor supply)	1	Saiz (2010)
δ_a Production externality	0.3	Ahlfeldt et al. (2015)
ρ_a Spatial decay	0.08	Ahlfeldt et al. (2015)
δ_b Production externality	0.15	Ahlfeldt et al. (2015)
ρ_b Spatial decay	0.03	Ahlfeldt et al. (2015)
ϵ Amenity dispersion	4	Ahlfeldt et al. (2015)

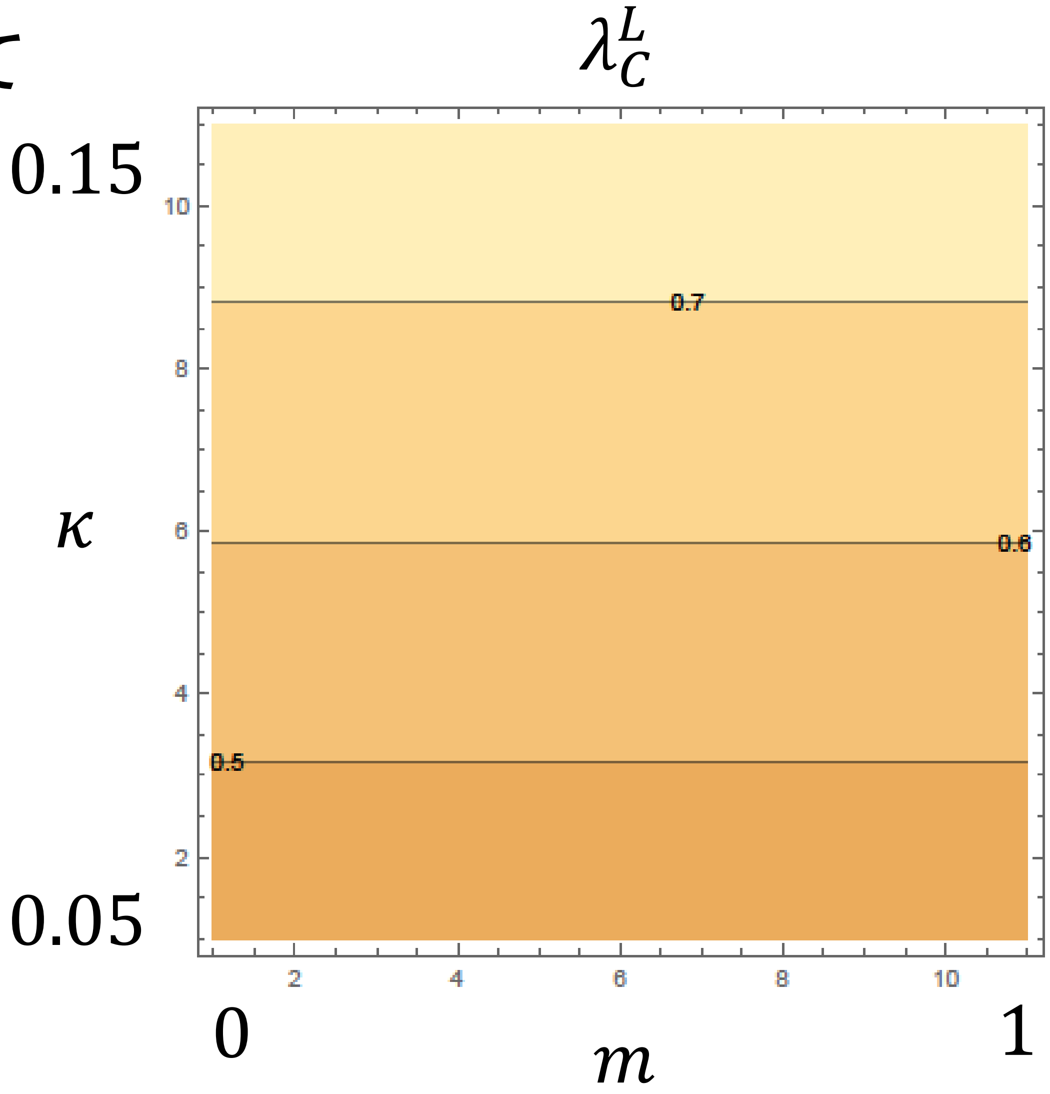
Numerical Calculation

- 数値計算
  - 設定
  - 外生変数

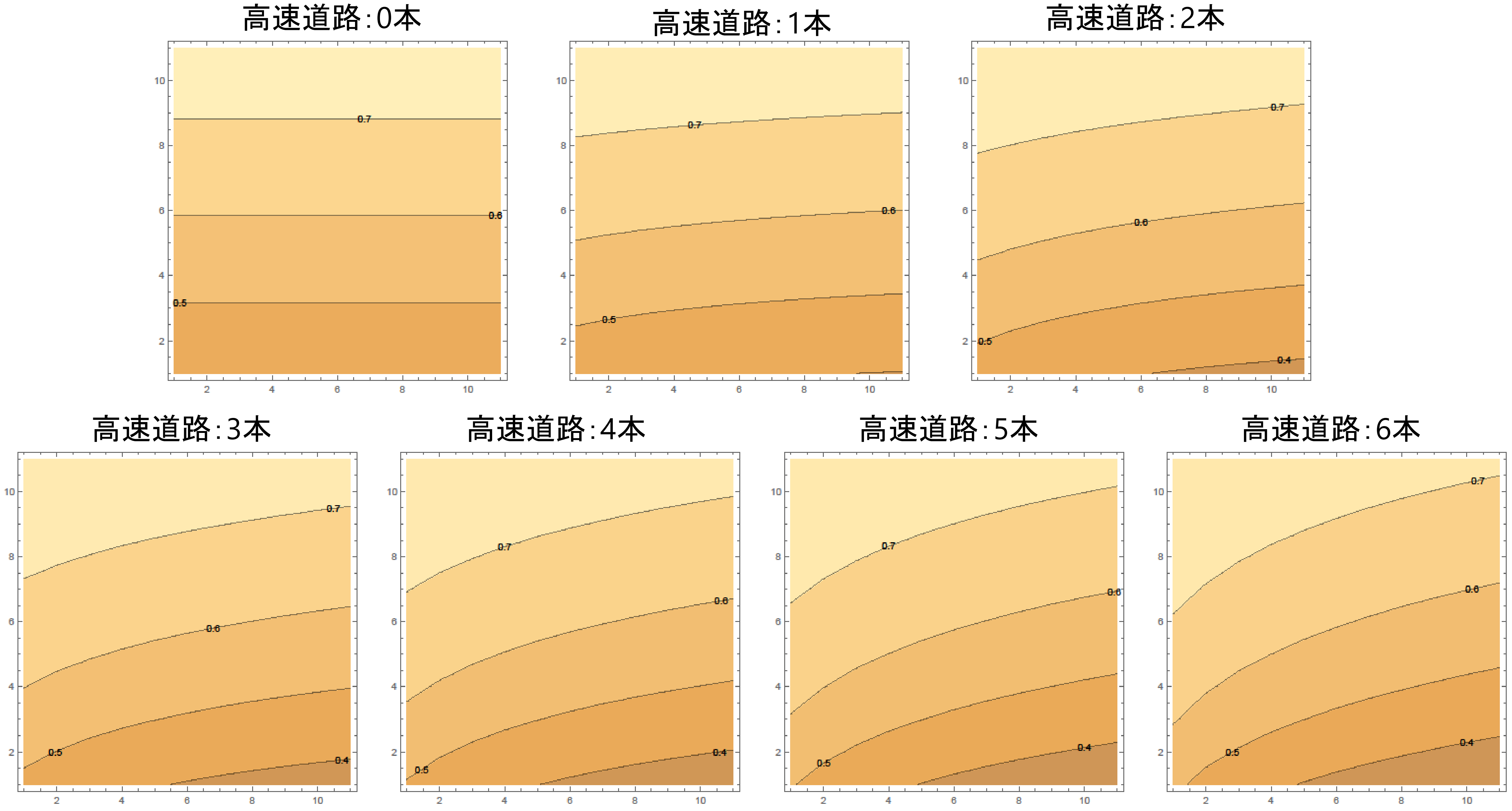
Exogenous variable	value	
K_c Land area in c	30	The average of land area of central city in 1950 in the United States
K_{s_f} Land area in s	300	$\sum_f^{Sub} K_{s_f} / Sub$: the average land area of suburban area in 1950
b_i Average amenities	1	
a_i Production (exogenous)	1	
M cities	7	Central city 1, suburban city 6
P Final good price	1	numéraire good

Numerical Calculation

- 数値計算の結果について
  - $\kappa : 0.05 \leq \kappa \leq 0.15$
  - $m : 0 \leq m \leq 1$

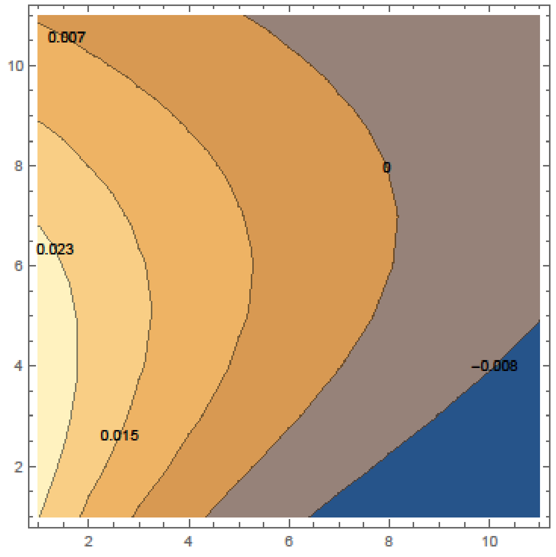


λ_C^L：中心都市の労働者の割合



高速道路建設がλ_C^Lに与える影響

0本 → 1本



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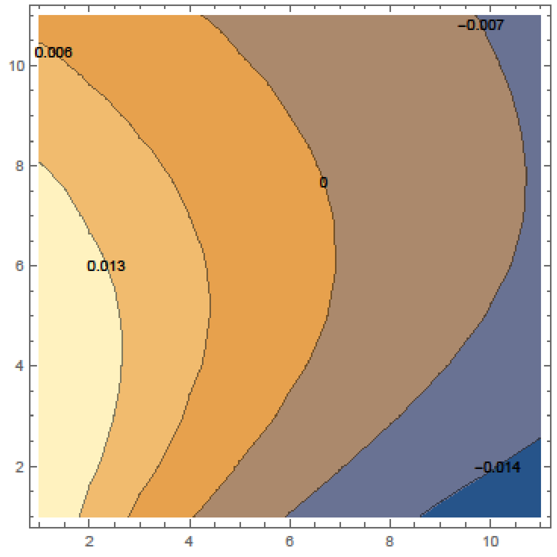
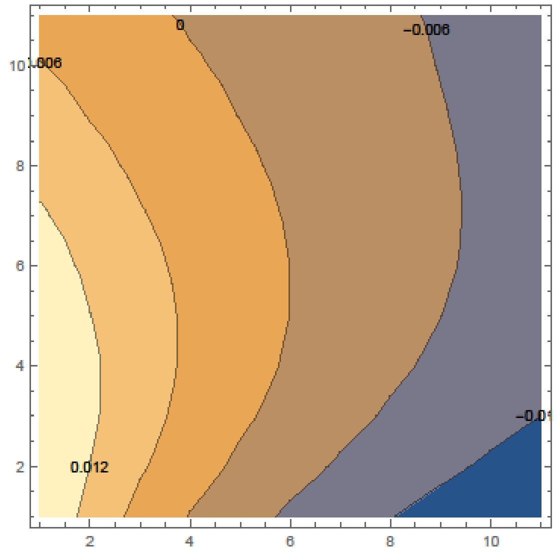


2本 → 3本



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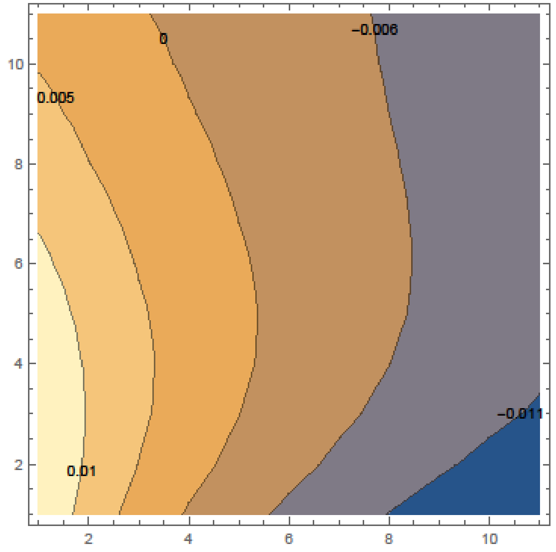
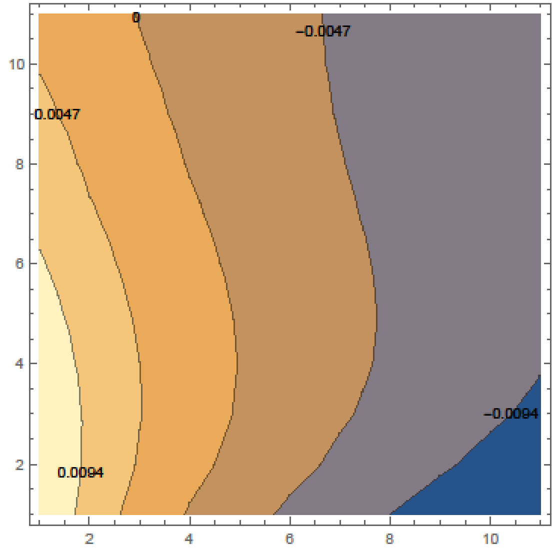


4本 → 5本



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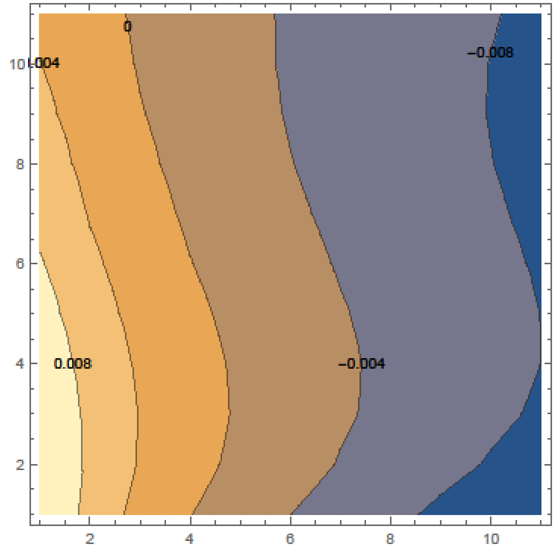
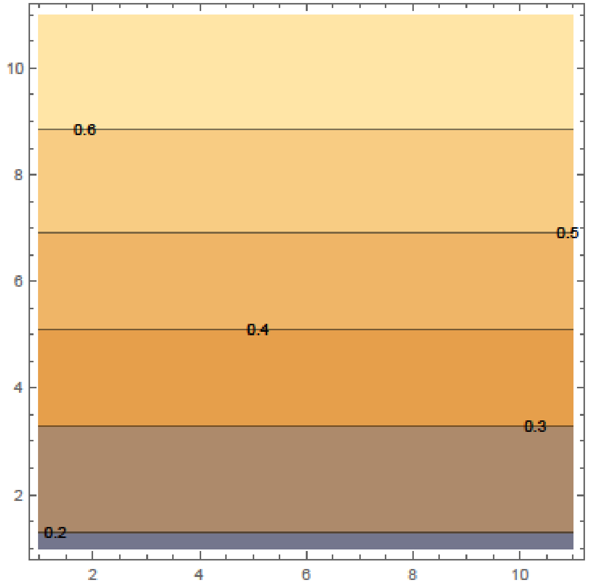


λ_C^R : 中心都市の居住者数の割合

高速道路:0本



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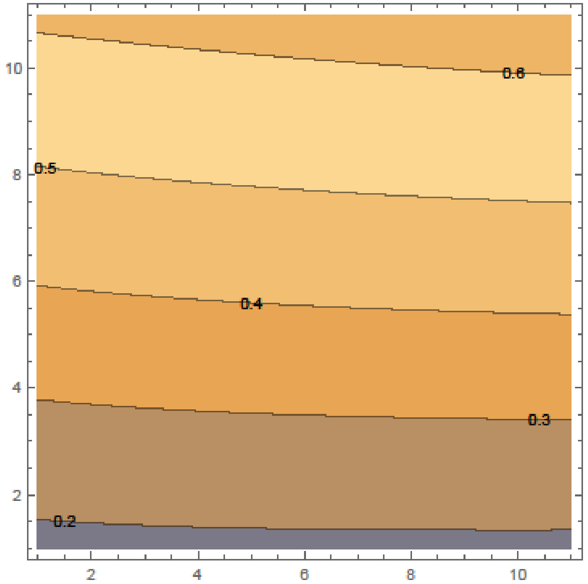

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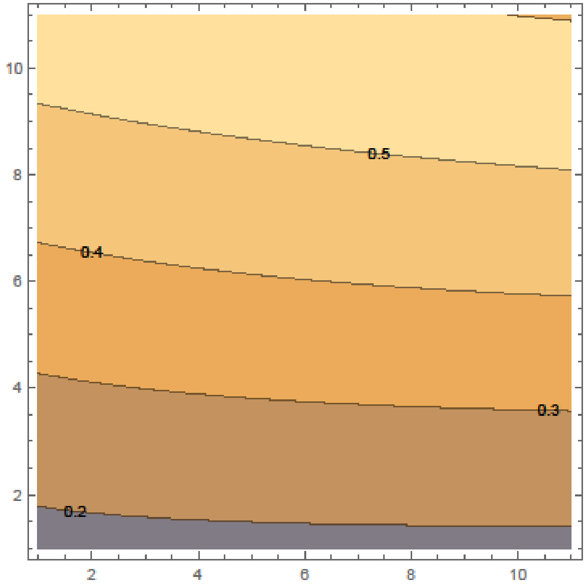

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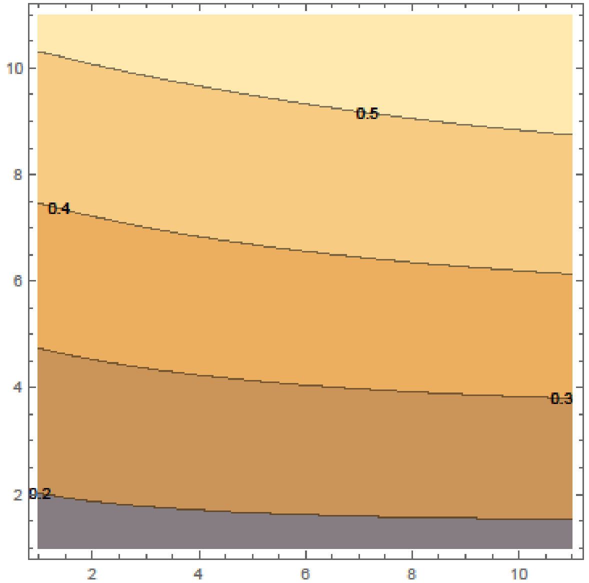

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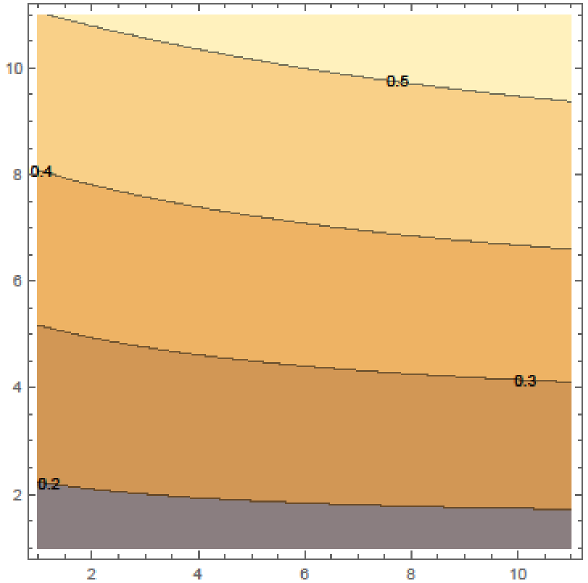

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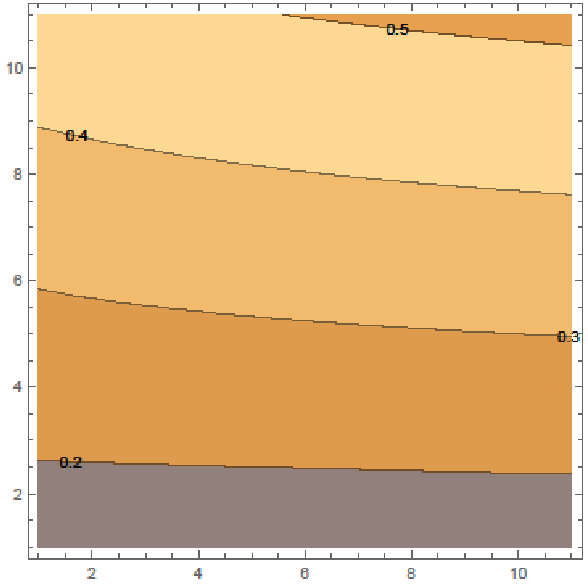
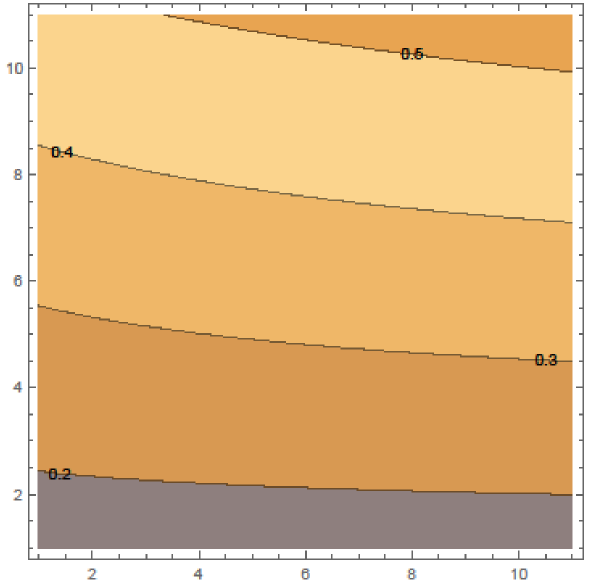
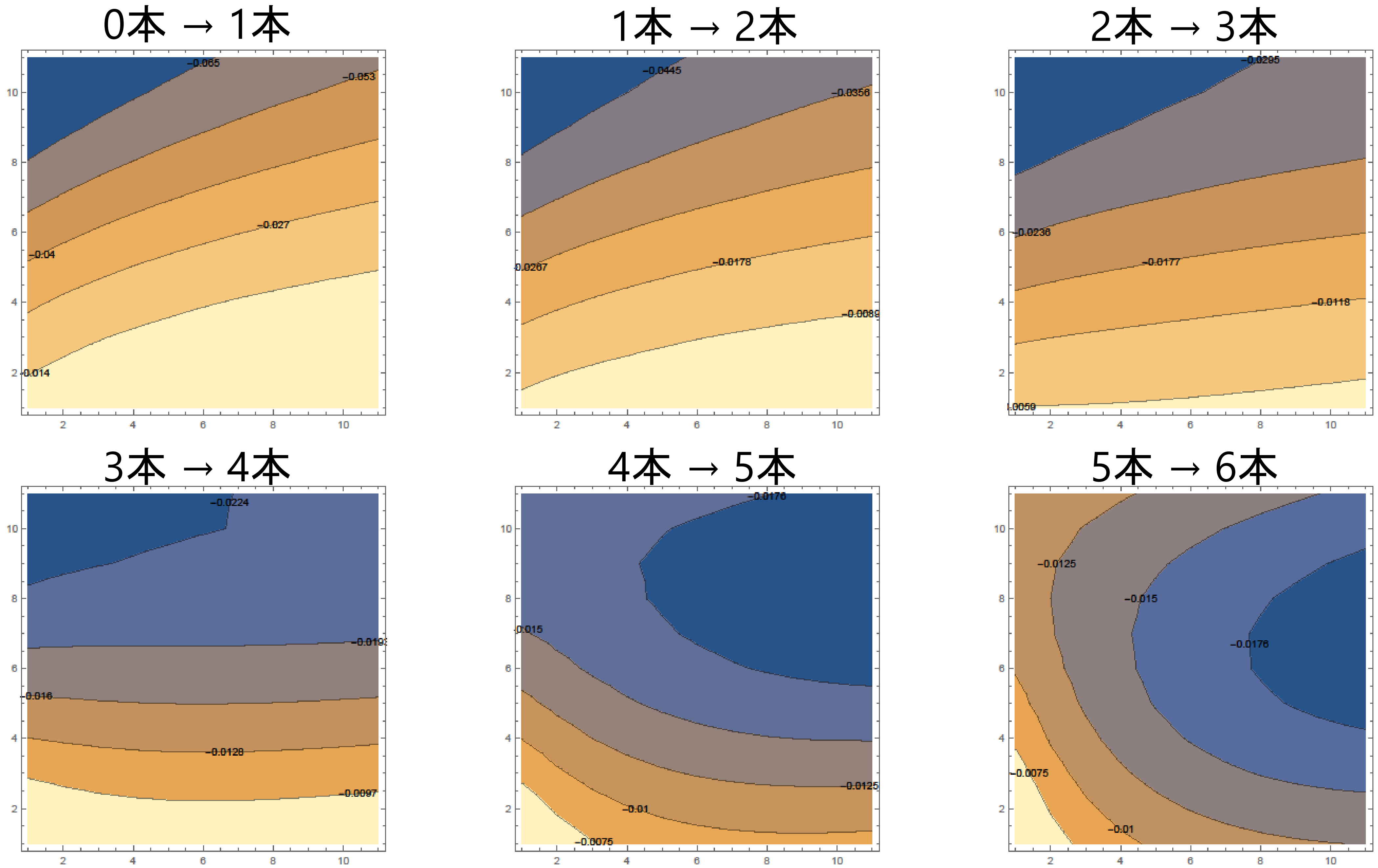


高速道路:6本

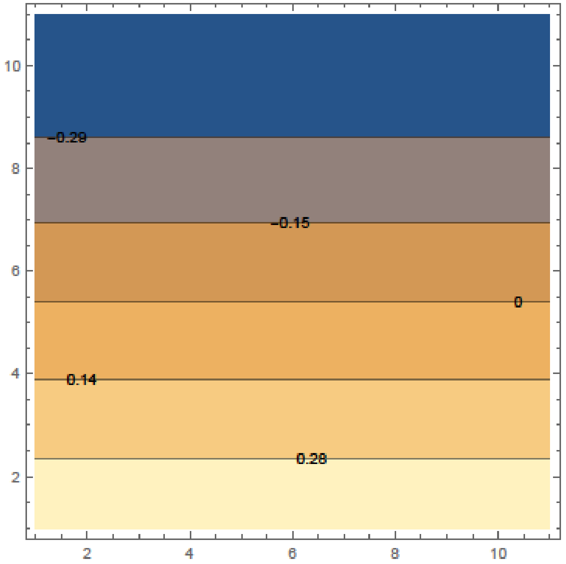


高速道路建設がλ_C^Rに与える影響

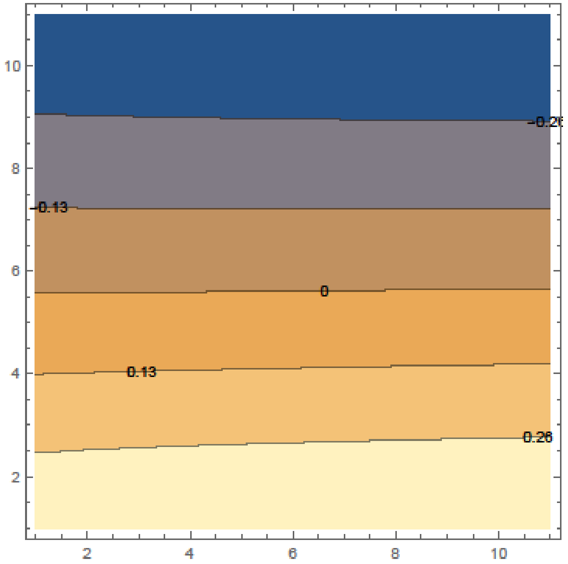


λ_{sc}: 郊外から中心都市への通勤者の割合

高速道路:0本



高速道路:1本



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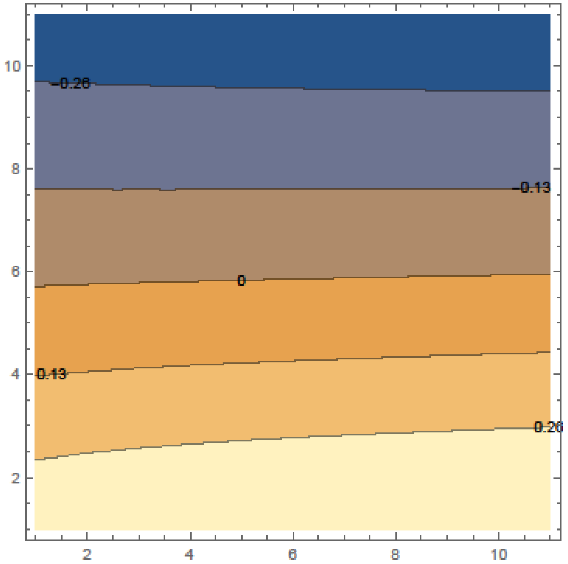

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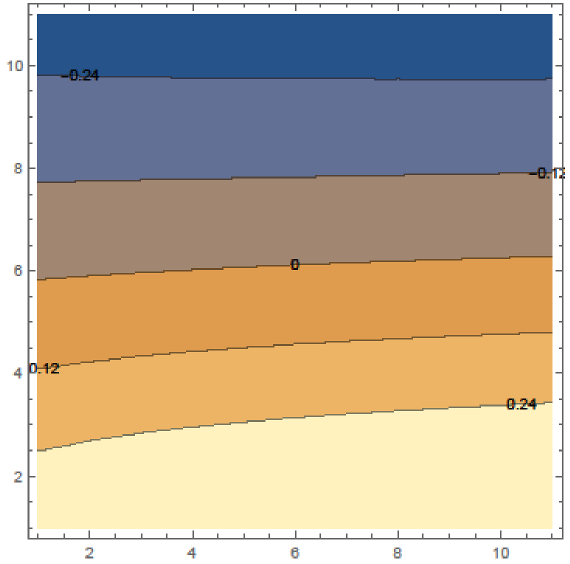

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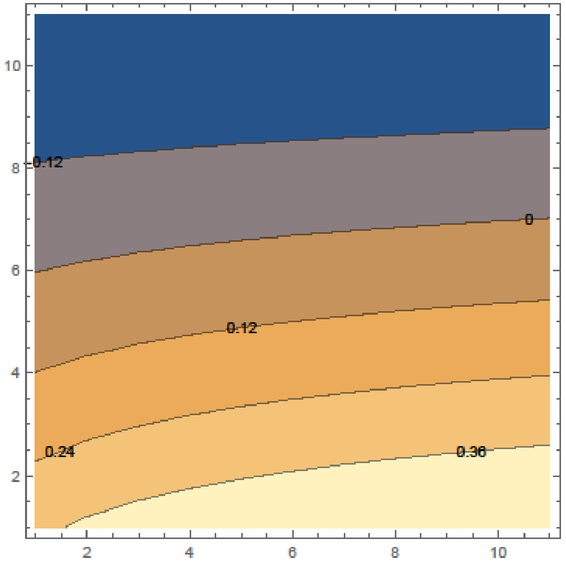

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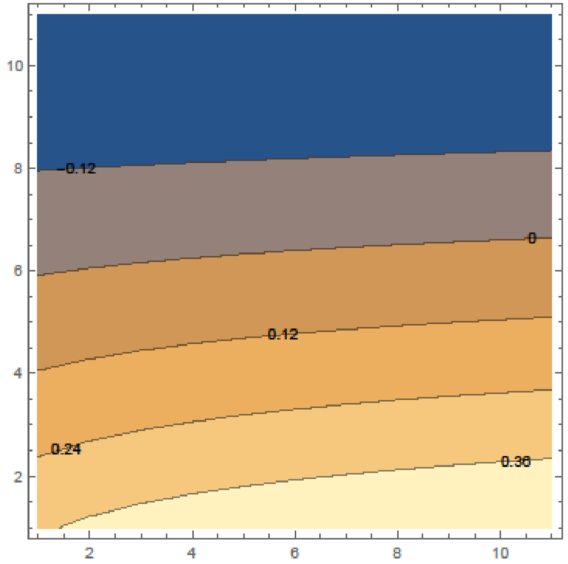
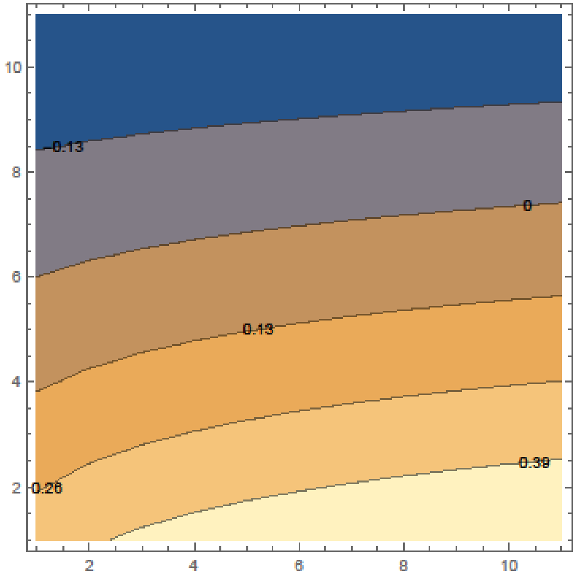


高速道路:6本



高速道路建設が λ_{sc} に与える影響

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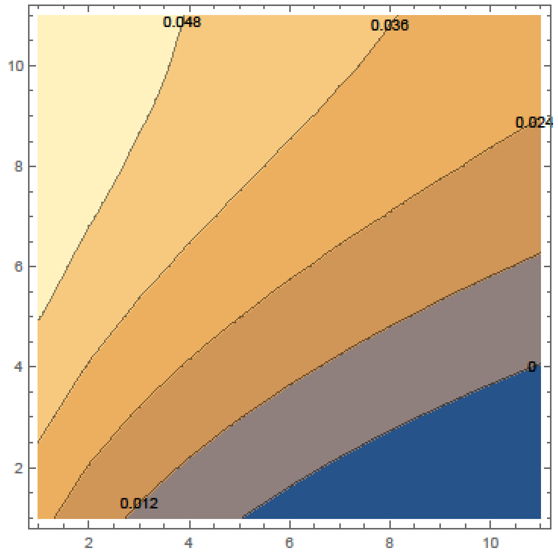

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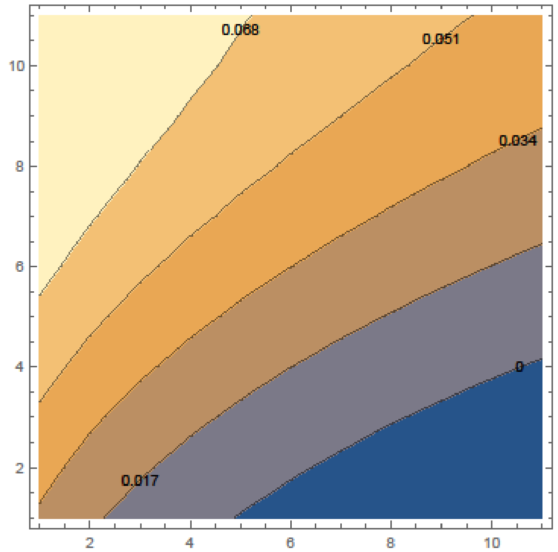

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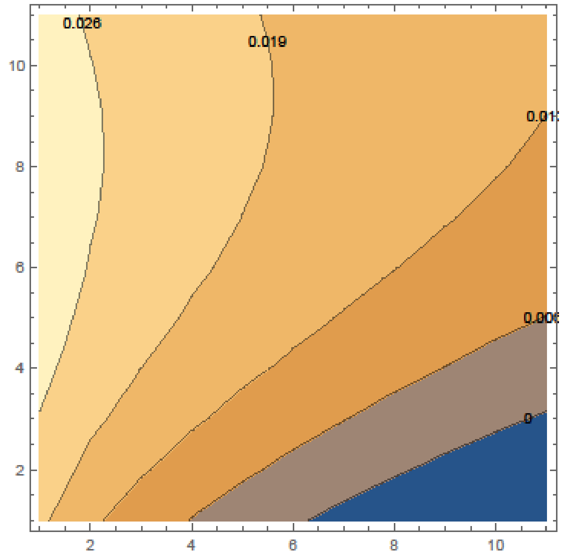

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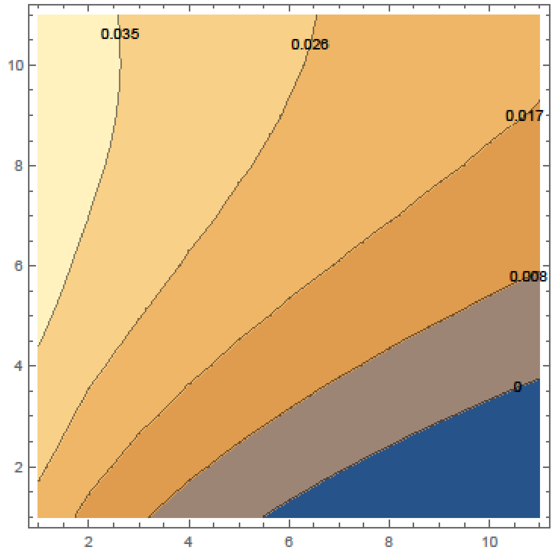

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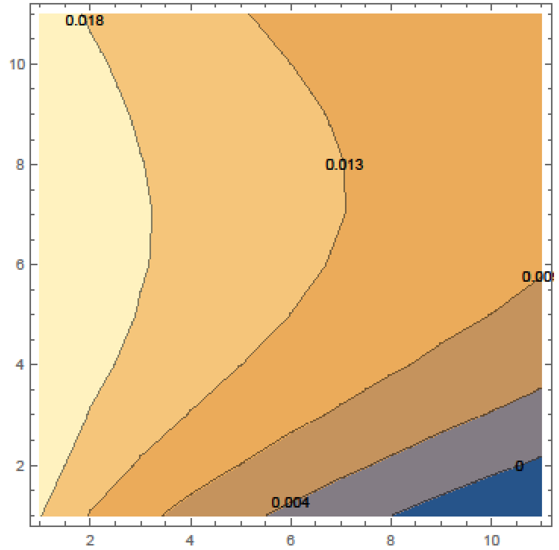

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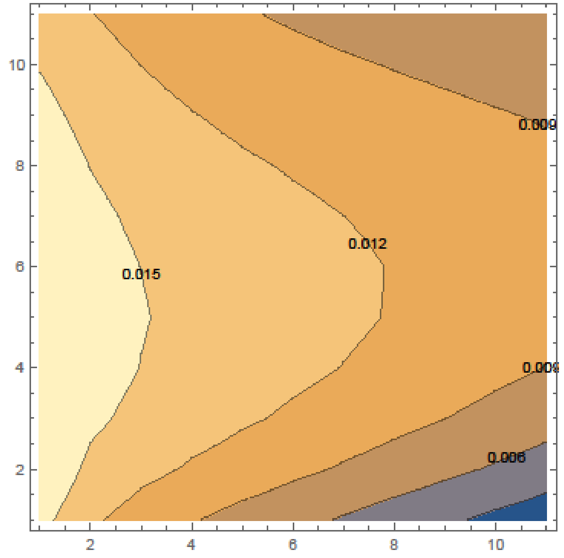
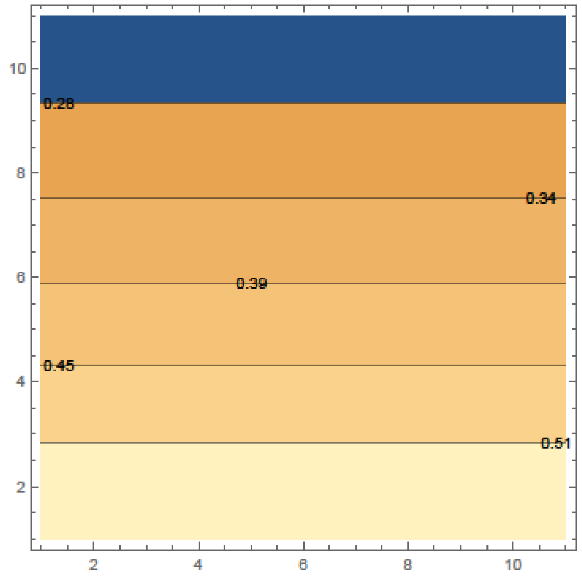
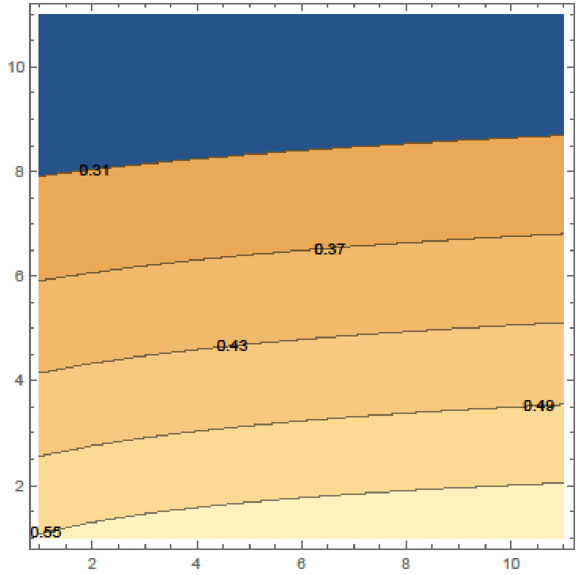


λ_{ss}: 郊外に住む、かつ働く人の割合

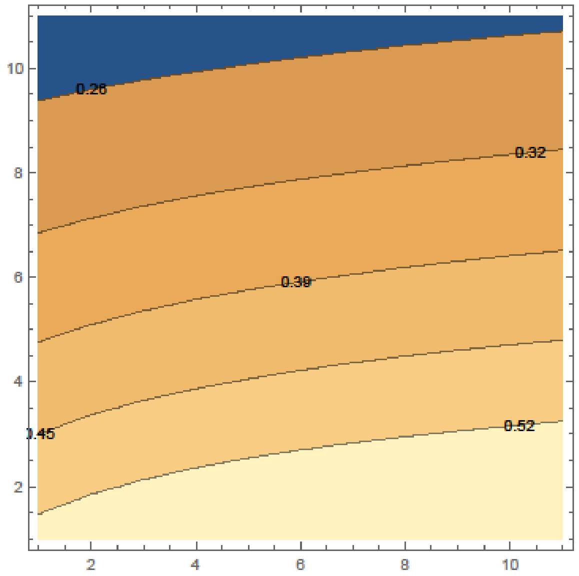
高速道路：0本



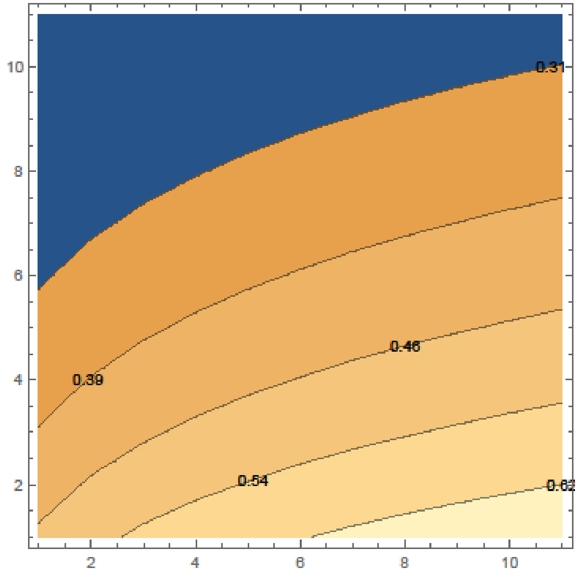
高速道路：1本



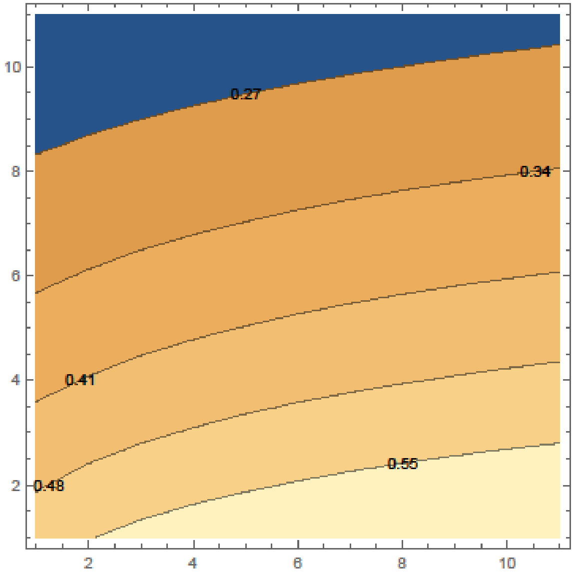
高速道路：2本



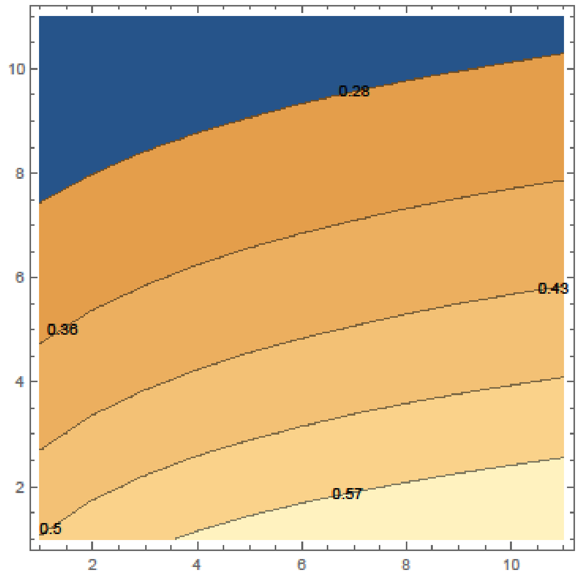
高速道路：3本



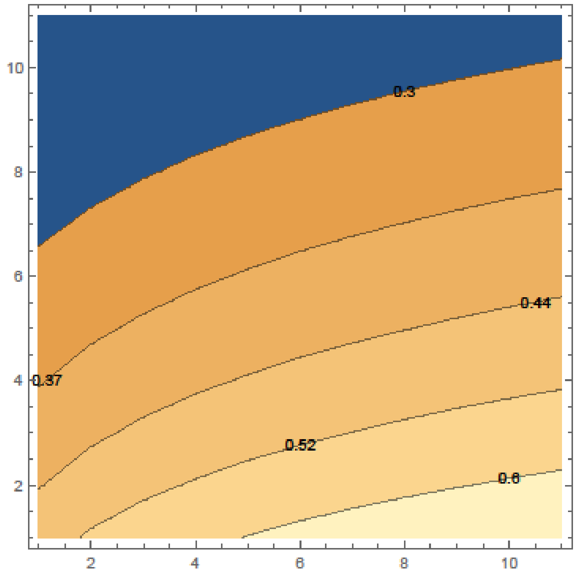
高速道路：4本



高速道路：5本

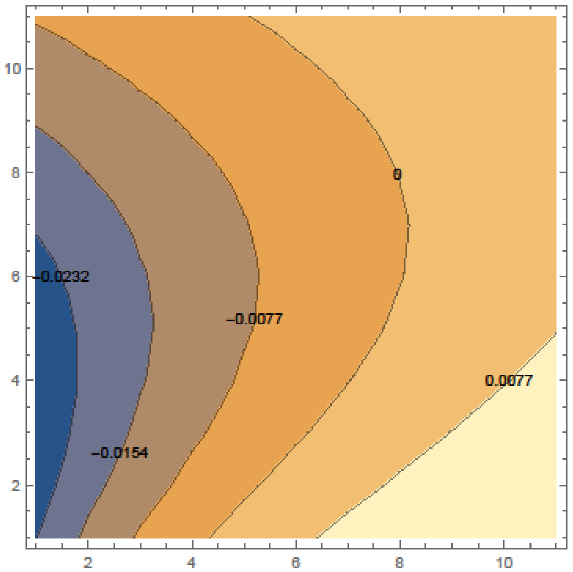


高速道路：6本

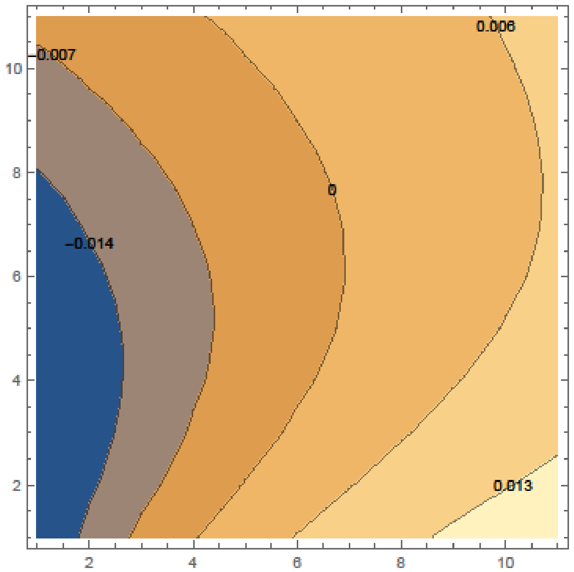


高速道路建設が λ_{ss} に与える影響

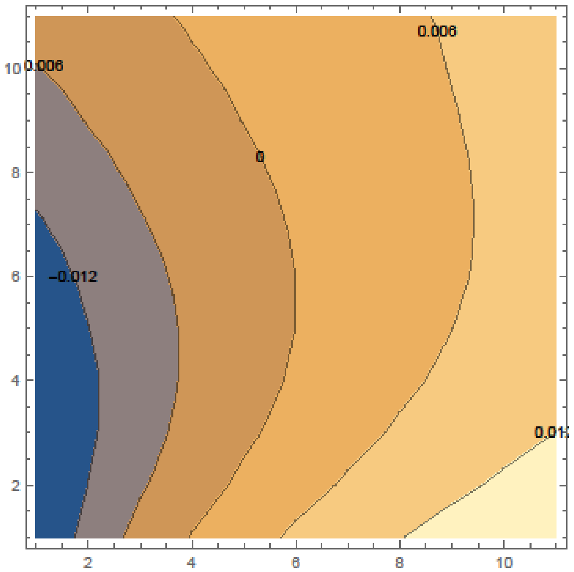
0本 → 1本



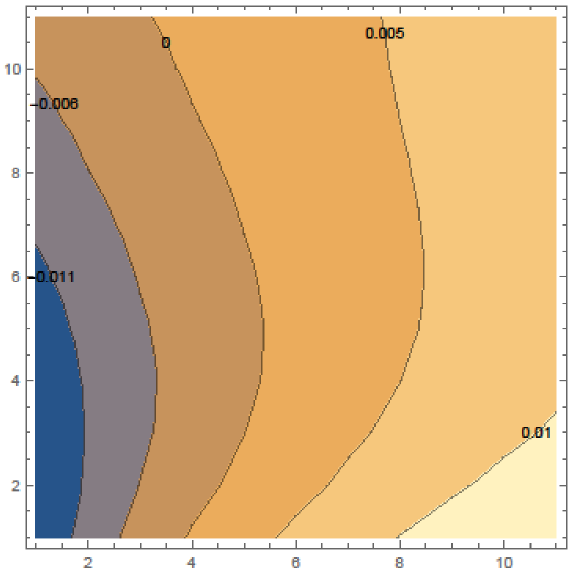
1本 → 2本



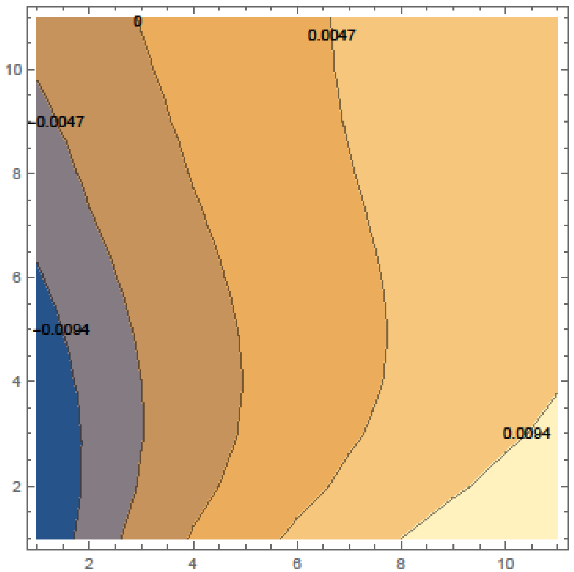
2本 → 3本



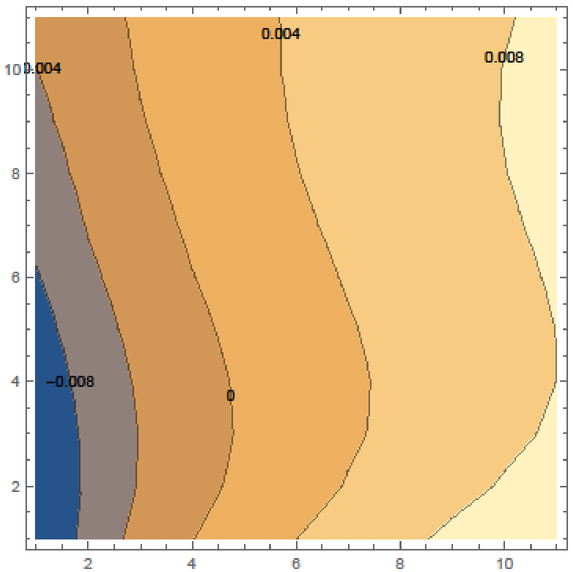
3本 → 4本



4本 → 5本

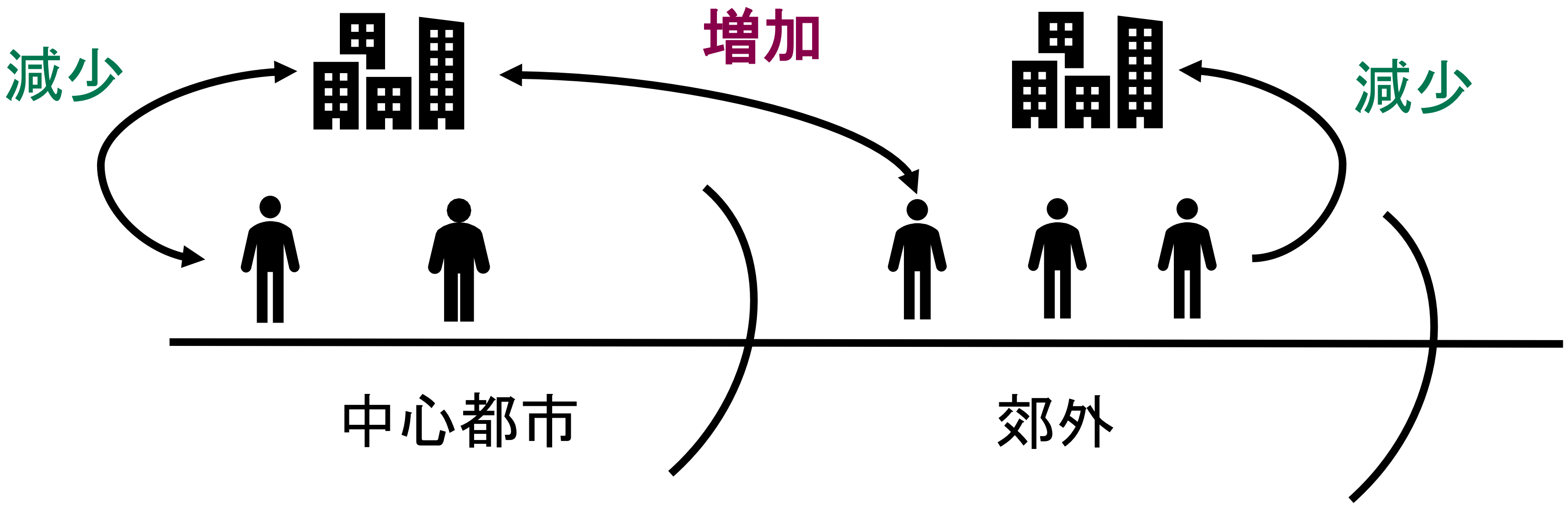


5本 → 6本



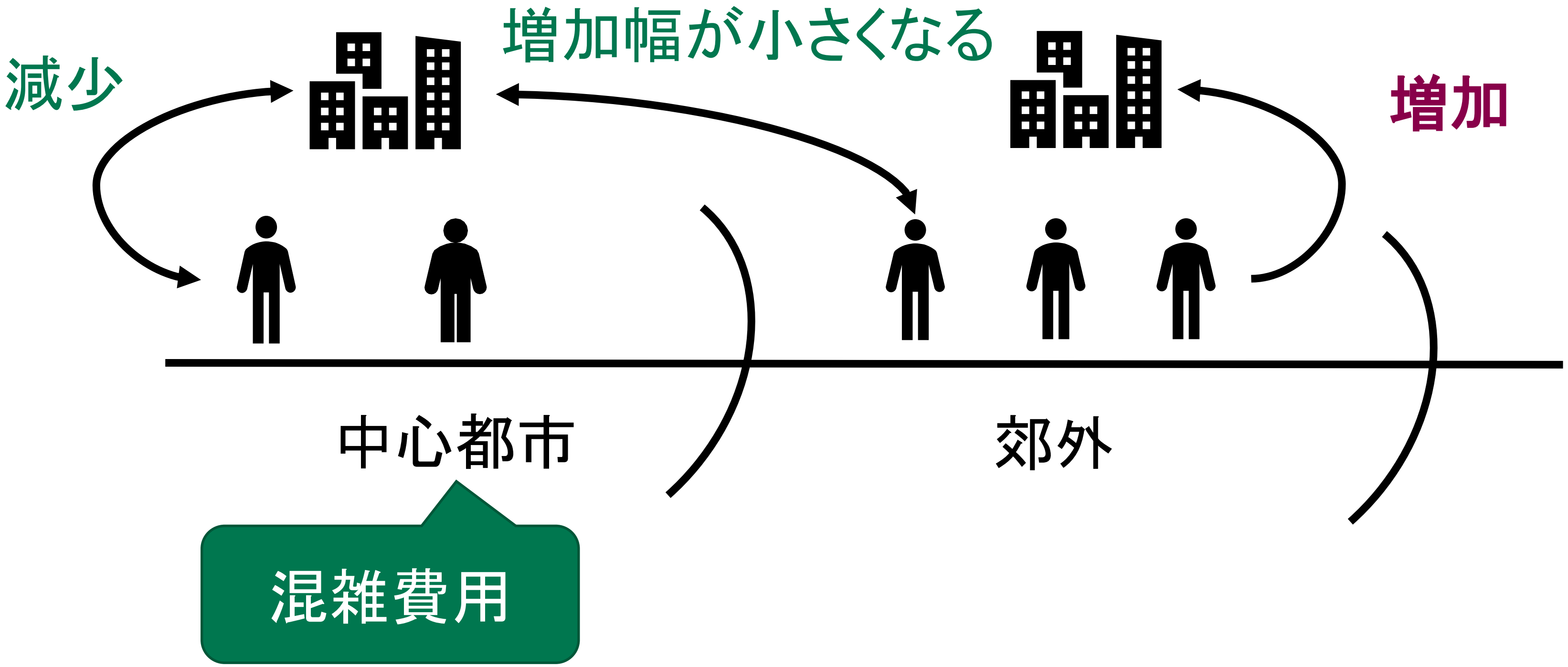
Numerical Calculation

- 郊外化のメカニズム
  - 混雑がない場合



Numerical Calculation

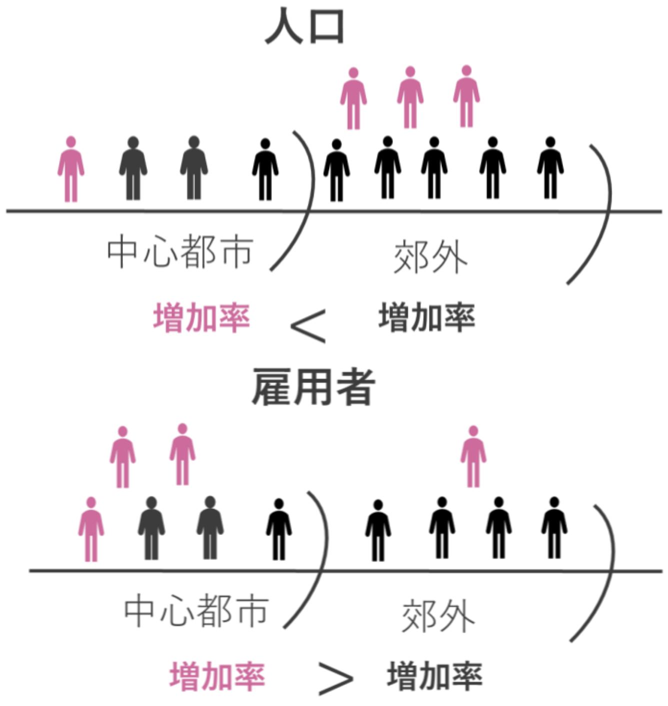
- 郊外化のメカニズム
  - 混雑ありの場合



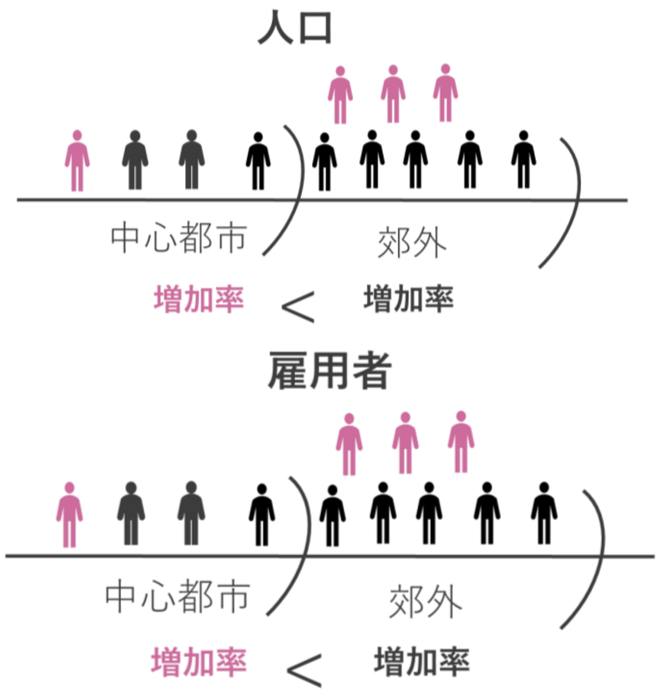
Numerical Calculation

郊外化のメカニズム

Canonical Urban Model
インフラの整備 → 通勤費用の低下 → 郊外化



提案モデル
交通インフラの整備 → 混雑の増加 → 郊外化



Robustness check

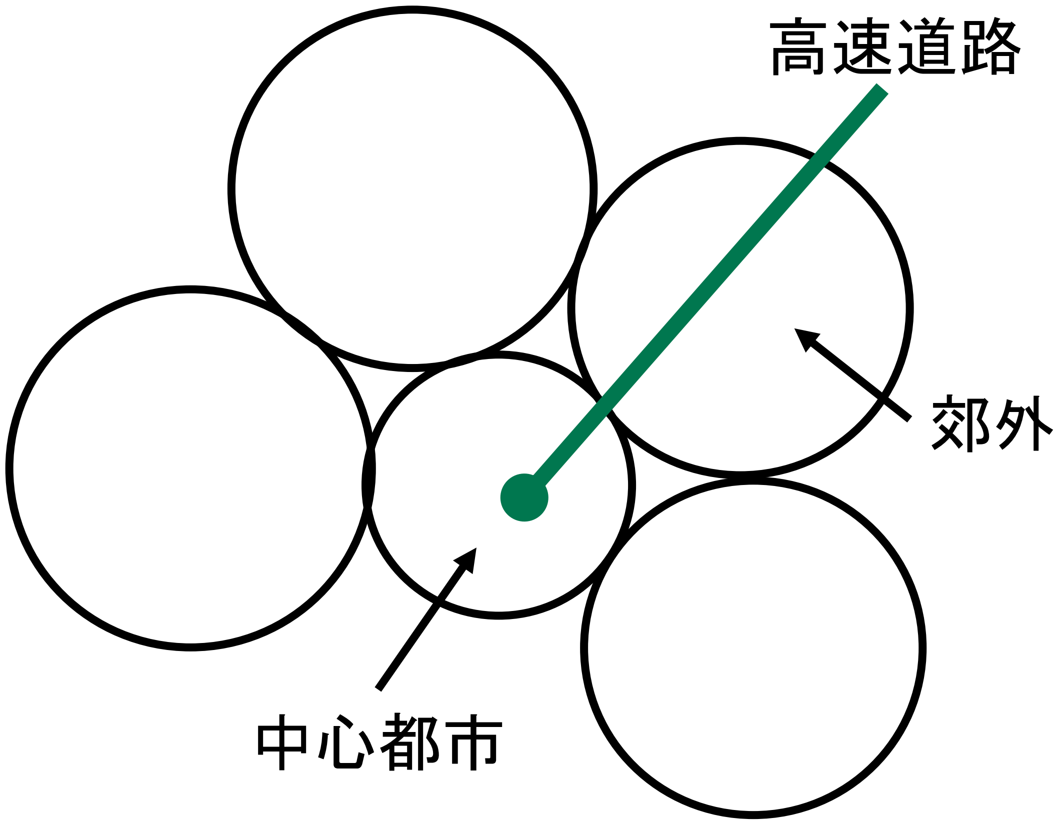
理論モデルの設定

- Heterogeneous Commuting Cost
- 高速道路と一般道
- Fundamental law of road congestion

混雑した高速道路は、一般道と速度が変わらない

→　高速道路が混雑している場合、

一般道を使用して通勤する



Robustness check

- Fundamental law of road congestion

$$k_{s_f c} = e^{\left[\boxed{\kappa_h + m(L_{s_f c} + L_{cc})}\right]\tau_{s_f c}}$$

$$k_{cc} = e^{\left\{\left[\boxed{(sub - n_h)\kappa + n_h(\kappa_h + m(L_{cc} + \sum_{i=1}^{\zeta} L_{s_i c}))}\right] / sub\right\}\tau_{cc}}$$

$$k_{s_i s_i} = e^{\left\{\boxed{\left[\kappa + (\kappa_k + mL_{s_i s_i})\right]/2}\right\}\tau_{s_i s_i}}$$

この部分が一般道の速度 κ を下回る場合、κ とする

数値計算の結果は、同じ

Guide to empirical analysis

- Baum-Snow (2007, *Q. J. Econ.*)
  - 推定式

$$p_j = \beta_0 + \beta_1 z_j + \boldsymbol{\beta X} + \varepsilon_j$$

p_j : $\log(CC\ pop.in\ 1990) - \log(CC\ pop.in\ 1950)$

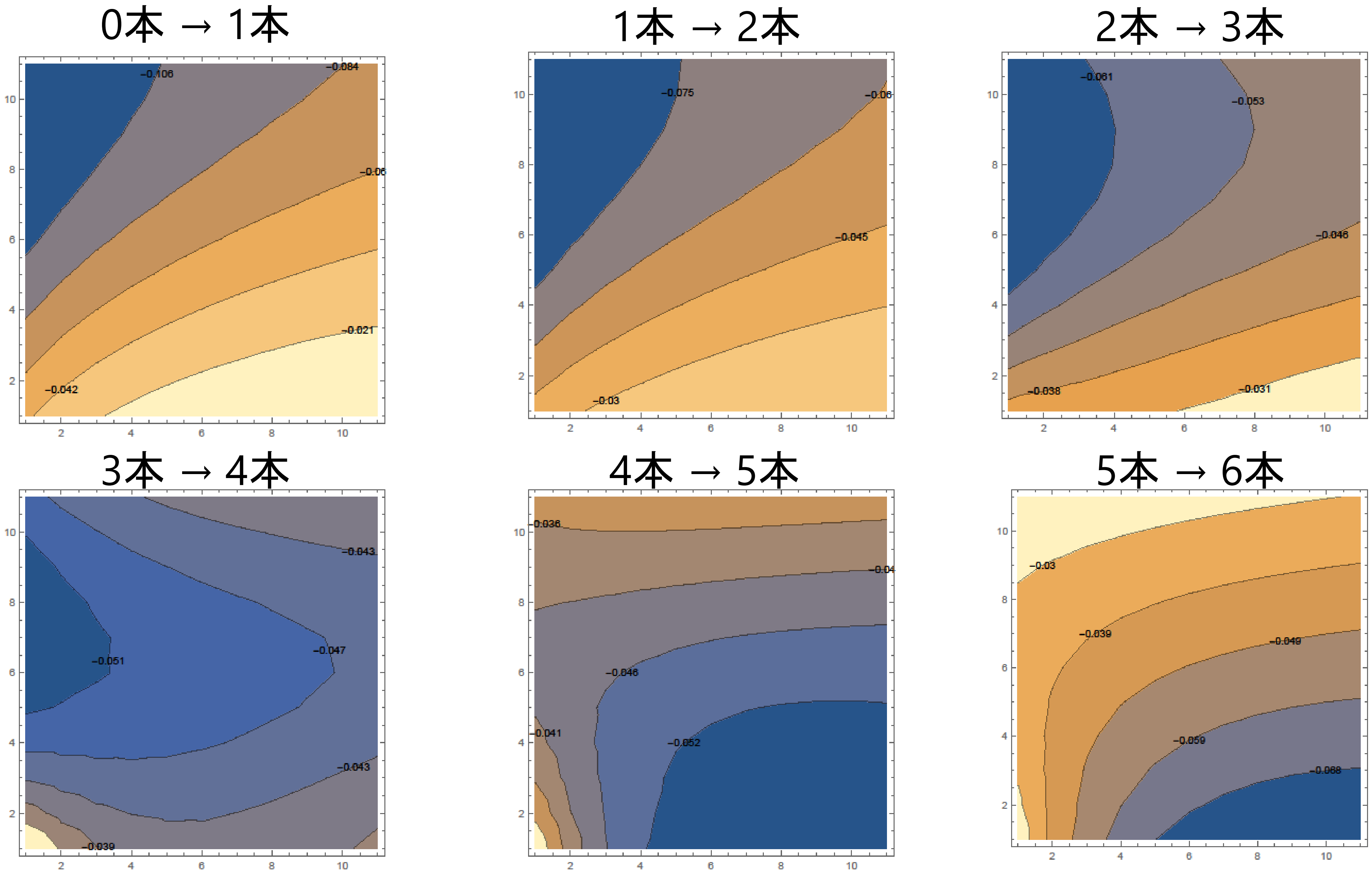
z_j : number of highway rays in the central city

Guide to empirical analysis

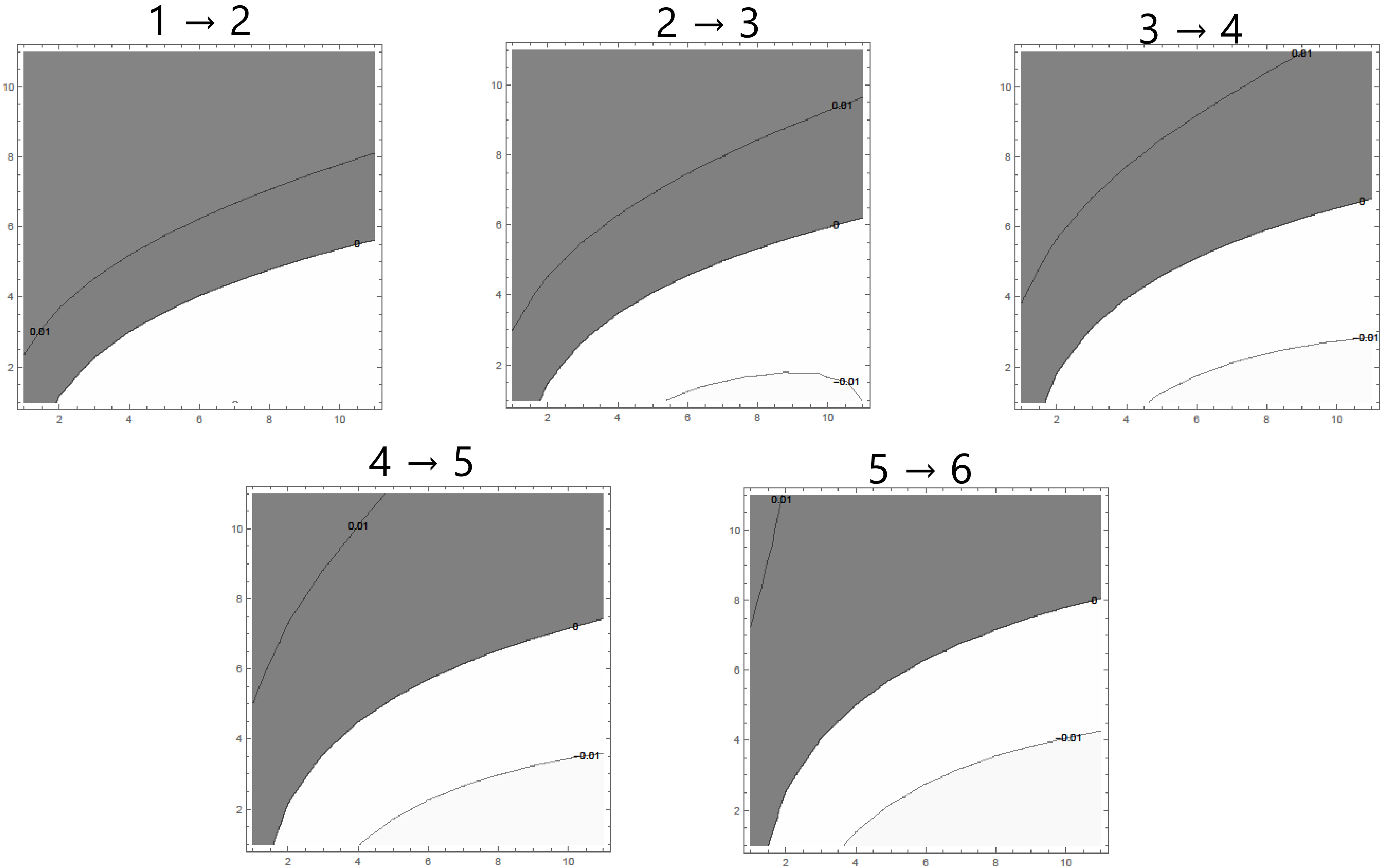
- 理論モデル
  - Canonical Urban Model と提案モデルの違い

$$\underbrace{\Delta \log \mathrm{CCpop}}_{\text{中心都市の人口変化}} - \underbrace{\Delta \log \bar{L}}_{\text{都市圏内の人口変化}}$$

$\Delta \log \mathrm{CCpop} - \Delta \log \bar{L}$

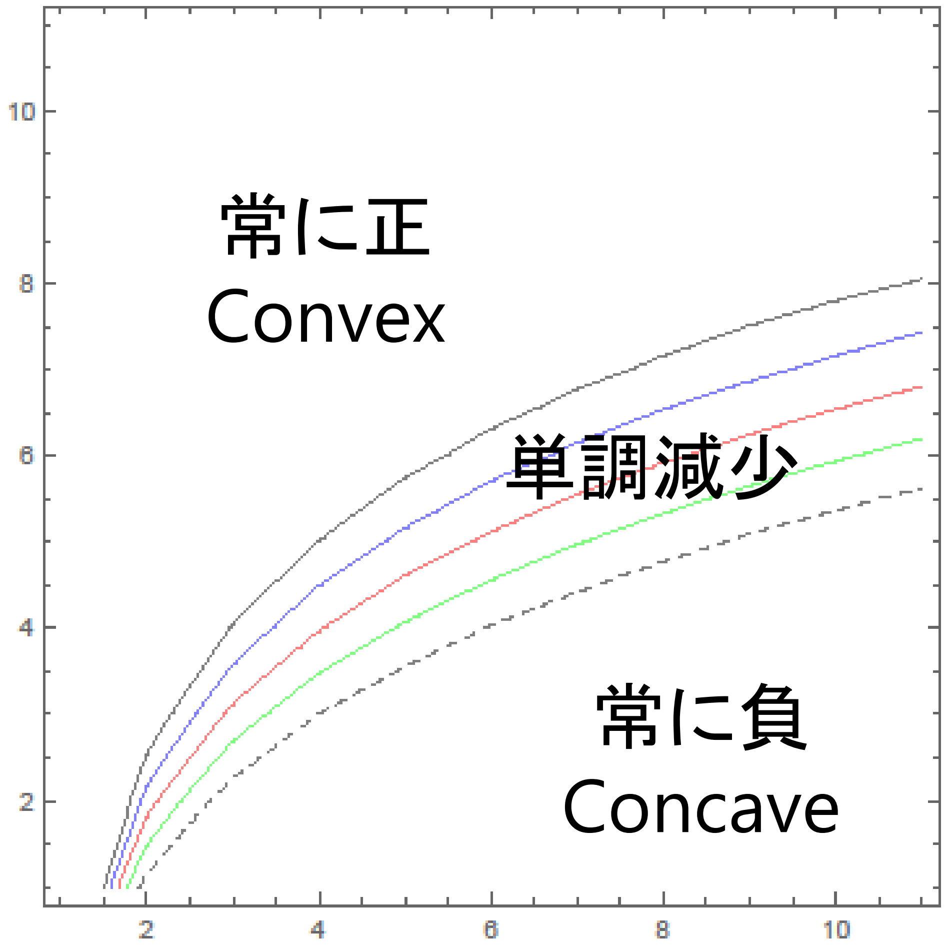


$\Delta \log \mathrm{CCpop} - \Delta \log \bar{L}$ の差分（2階の微分）

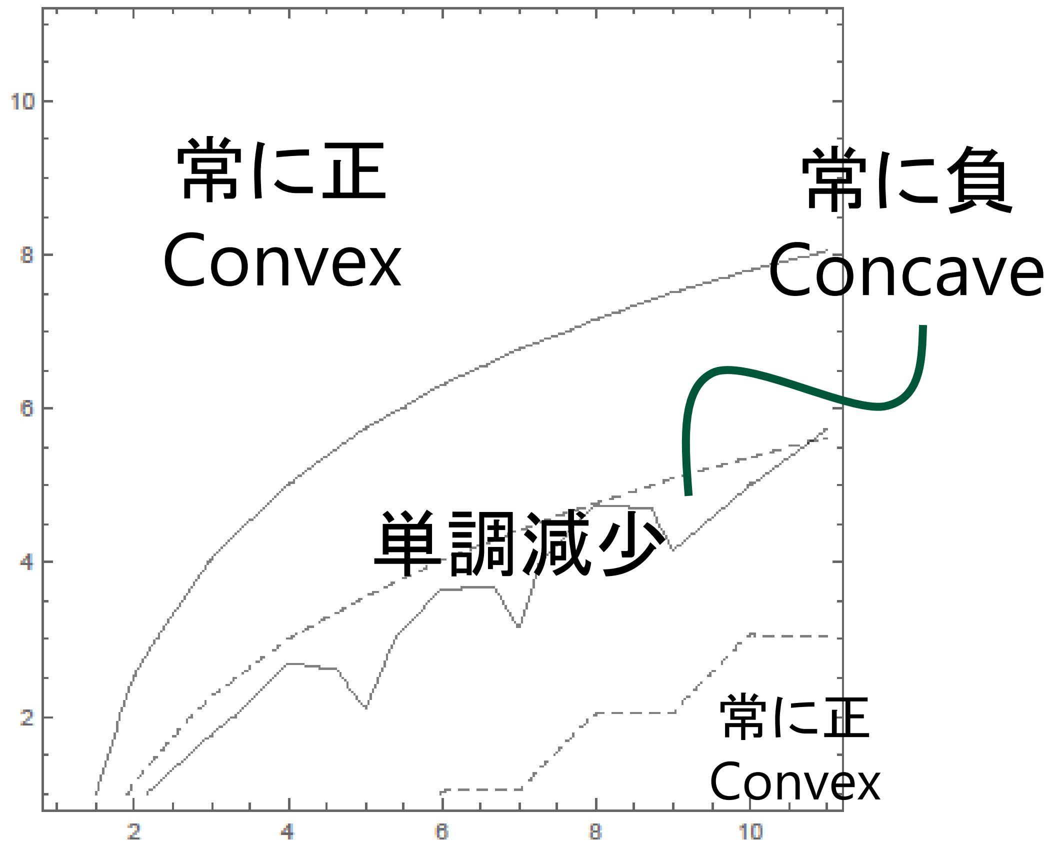


Guide to empirical analysis

- $\Delta \log \mathrm{CCpop} - \Delta \log \bar{L}$ の差分（2階の微分）

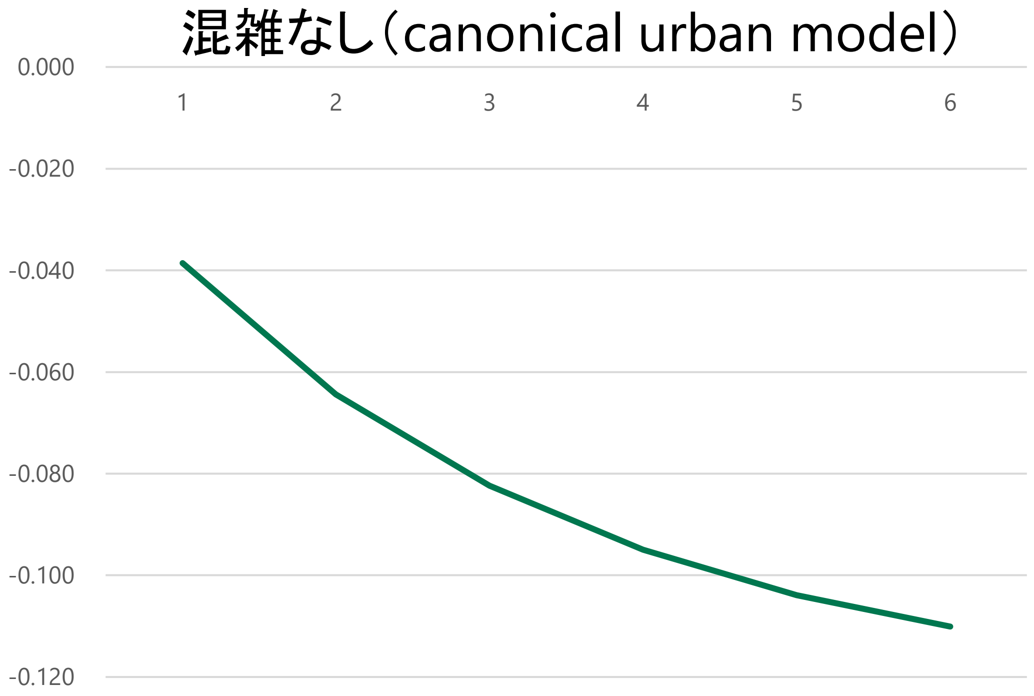


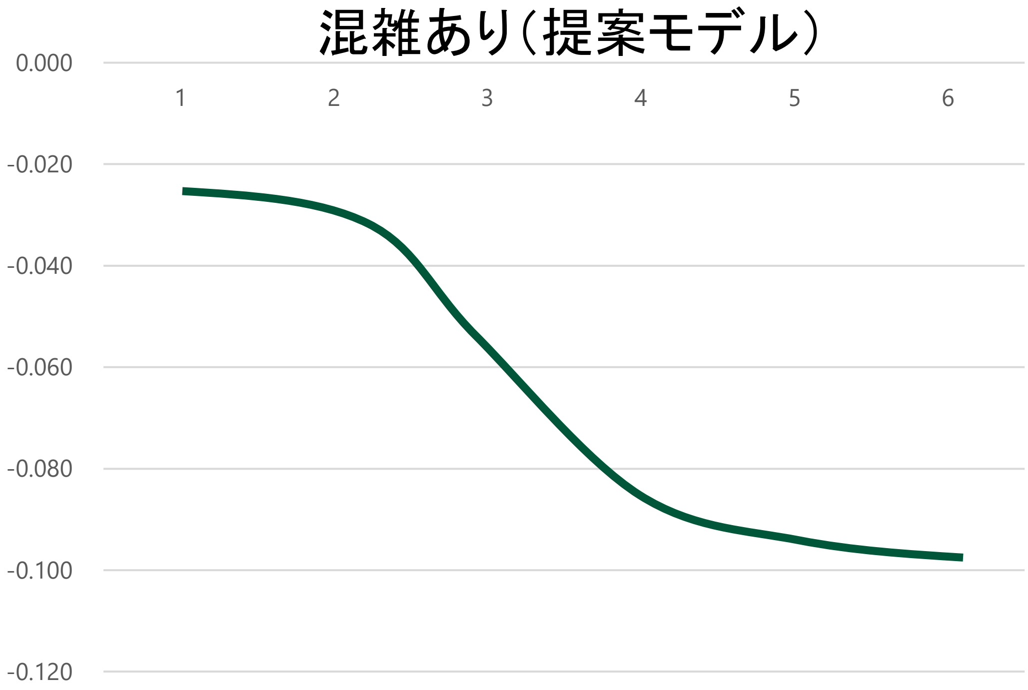
Fundamental law を考慮した場合



Guide to empirical analysis

- 理論モデル
  - Canonical Urban Model と提案モデルの違い
  - 実証研究における仮説





Data & Estimation Methodology

- データ
  - Baum-Snow (2007) と同じデータ

    アメリカ都市圏(240都市)のデータ

    1950年から1990年まで

    中心都市に着目

    州間高速道路 (Interstate highway) の建設

    1956年から建設開始

    1990年までにおよそ完成

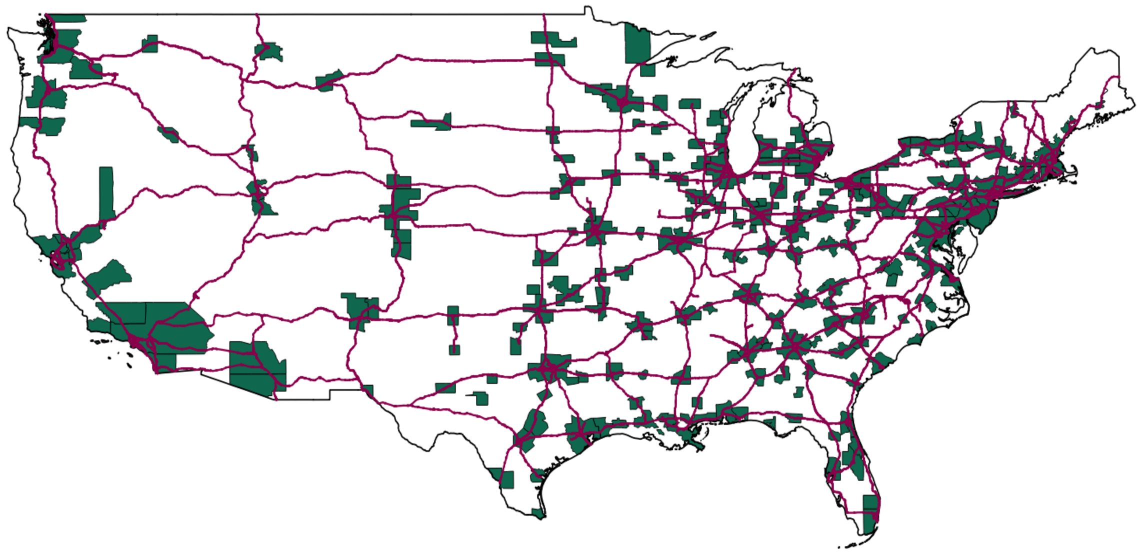


図　州間高速道路

Data & Estimation Methodology

- データ
  - インフラ整備はランダムに割り当てられるわけではない
  - 操作変数

    1947年の National System of Interstate Highways Plan

    この計画とのズレがある

    → 外生的割り当て

    Baum-Snow (2007), Michaels (2008),

    Duranton and Tuner (2011, 2012) などで使用

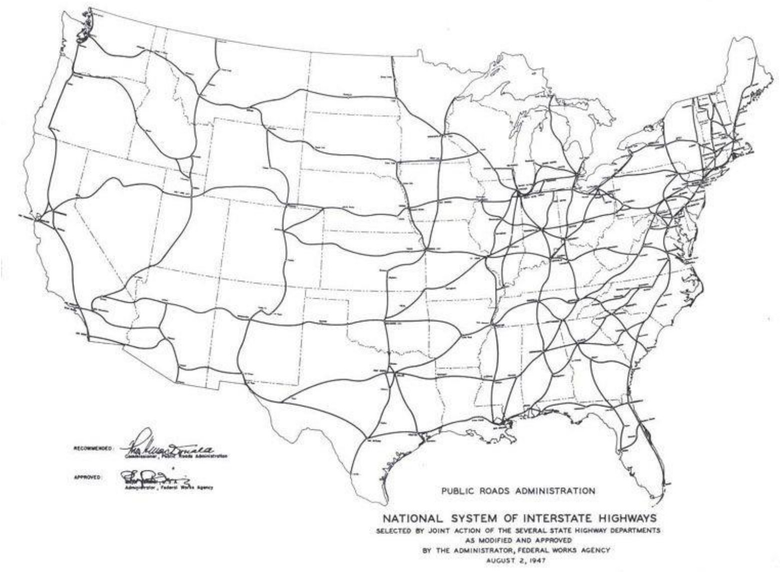
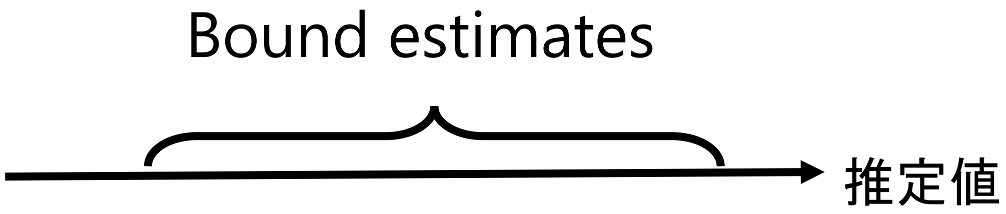


図　1947年の高速道路計画
出典：U.S. Department of Transportation

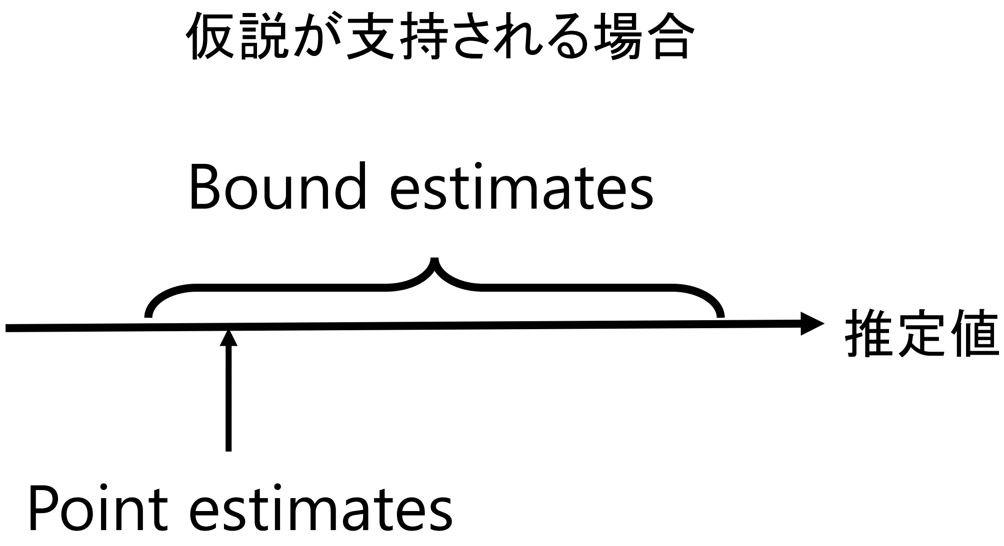
Data & Estimation Methodology

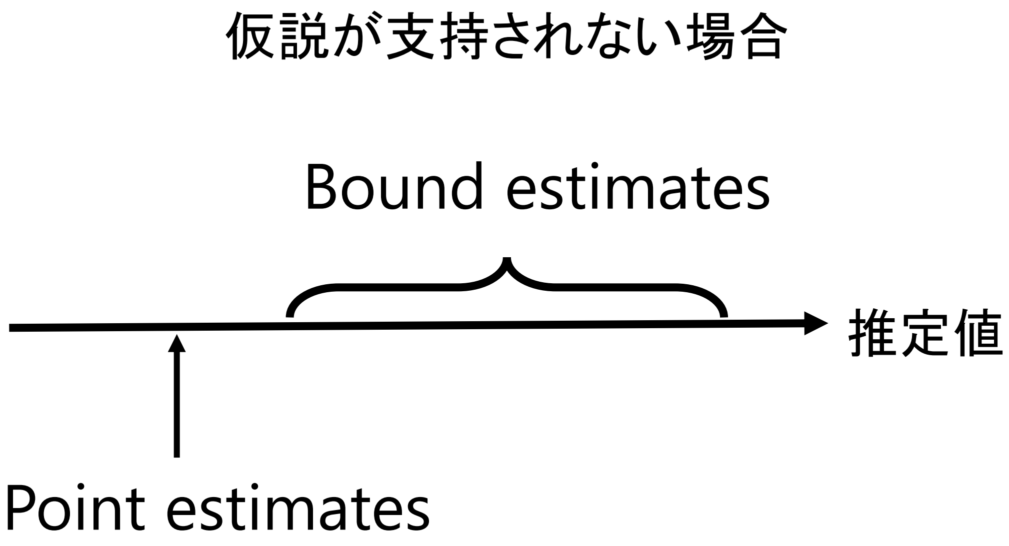
- 推定手法
  - 部分識別 → 因果効果が入る幅を推定
    - 単調減少関数を仮定 → 提案モデル
    - Convexかつ単調減少関数を仮定 → canonical urban model



Data & Estimation Methodology

- 推定手法
  - 部分識別





Data & Estimation Methodology

推定手法

部分識別

変数名

$p_j(t)$ ：高速道路が t 本のときの都市 j の1950年から1990年までの人口変化

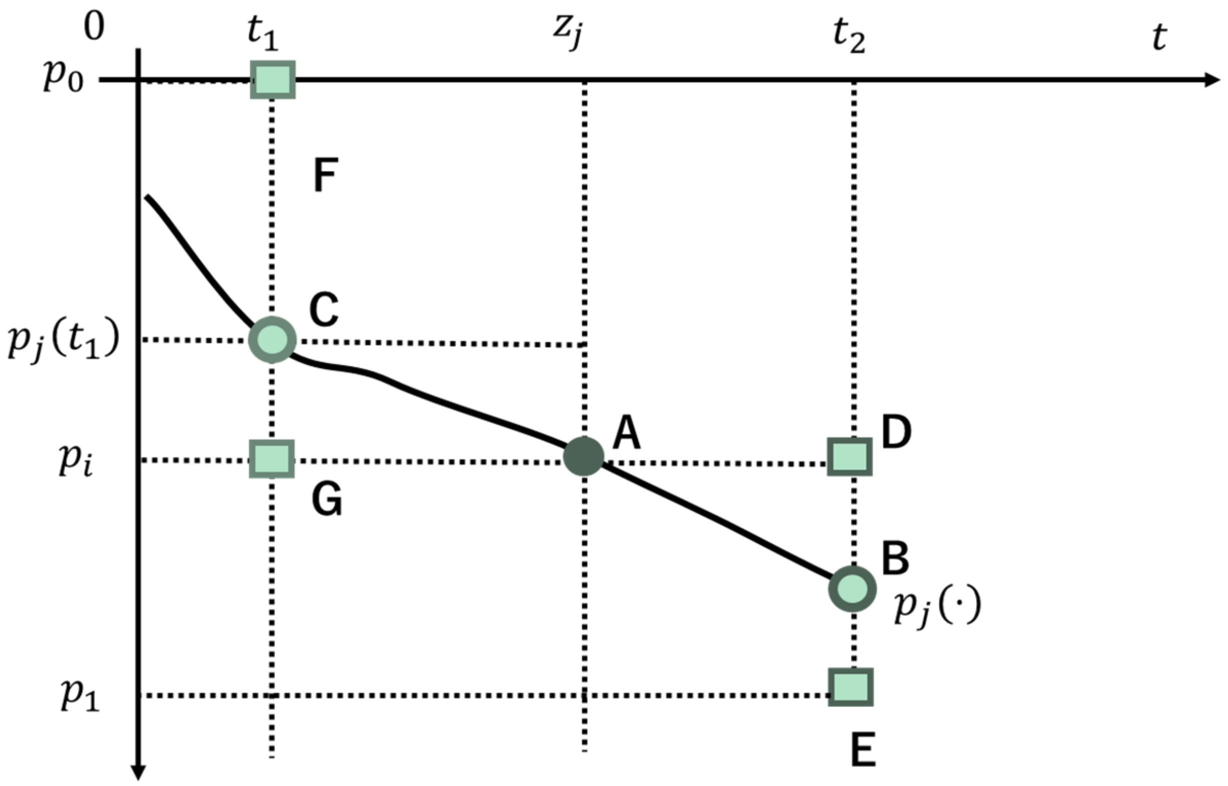
t ：中心都市を通る高速道路の本数（処置） $t \in T = \{1, 2, 3, 4, 5, 6\}$

z ：実現した処置（$p_j \equiv p_j(z_j)$）

Data & Estimation Methodology

推定手法

- 部分識別
- 単調減少関数：Manski (1997)



Data & Estimation Methodology

- 推定手法
  - 部分識別
  - 単調減少関数:Manski (1997)

$$\sum_{t \leq s} E[p|z = s] \Pr(z = s) + p_0 \Pr(z < t)$$

$$\leq E[p(t)] \leq$$

$$p_1 \Pr(z > t) + \sum_{s \leq t} E[p|z = s] \Pr(z = s),$$

Data & Estimation Methodology

推定手法

- 部分識別
- 単調減少関数: 平均処置効果 $(t_2 > t_1)$

$$\left[p_0 P(z > t_2) + \sum_{s \le t_2} E[p|z = s] \Pr(z = s) - \sum_{s \le t_1} E[p|z = s] \Pr(z = s) + p_1 \Pr(z < t)\right] / (t_2 - t_1)$$

$$\le \{E[p(t_2)] - E[p(t_1)]\} / (t_2 - t_1) \le 0$$

Data & Estimation Methodology

- 推定手法
  - 部分識別
  - 操作変数 Manski and Pepper, (2000): 操作変数の除外制約の仮定

$$E[p(t)|v = u_1] = E[p(t)|v = u_2] = E[p(t)]$$

Data & Estimation Methodology

- 推定手法
  - 部分識別
  - 単調減少関数 + 操作変数

$$\max_{u\in V}\left\{\sum_{t\leq s} E[p|z=s,v=u]\Pr(z=s|v=u)+p_0\Pr(z<t|v=u)\right\}$$

$$\leq E[p(t)] \leq$$

$$\min_{u\in V}\left\{p_1\Pr(z>t|v=u)+\sum_{s\leq t} E[p|z=s,v=u]\Pr(z=s|v=u)\right\}.$$

Data & Estimation Methodology

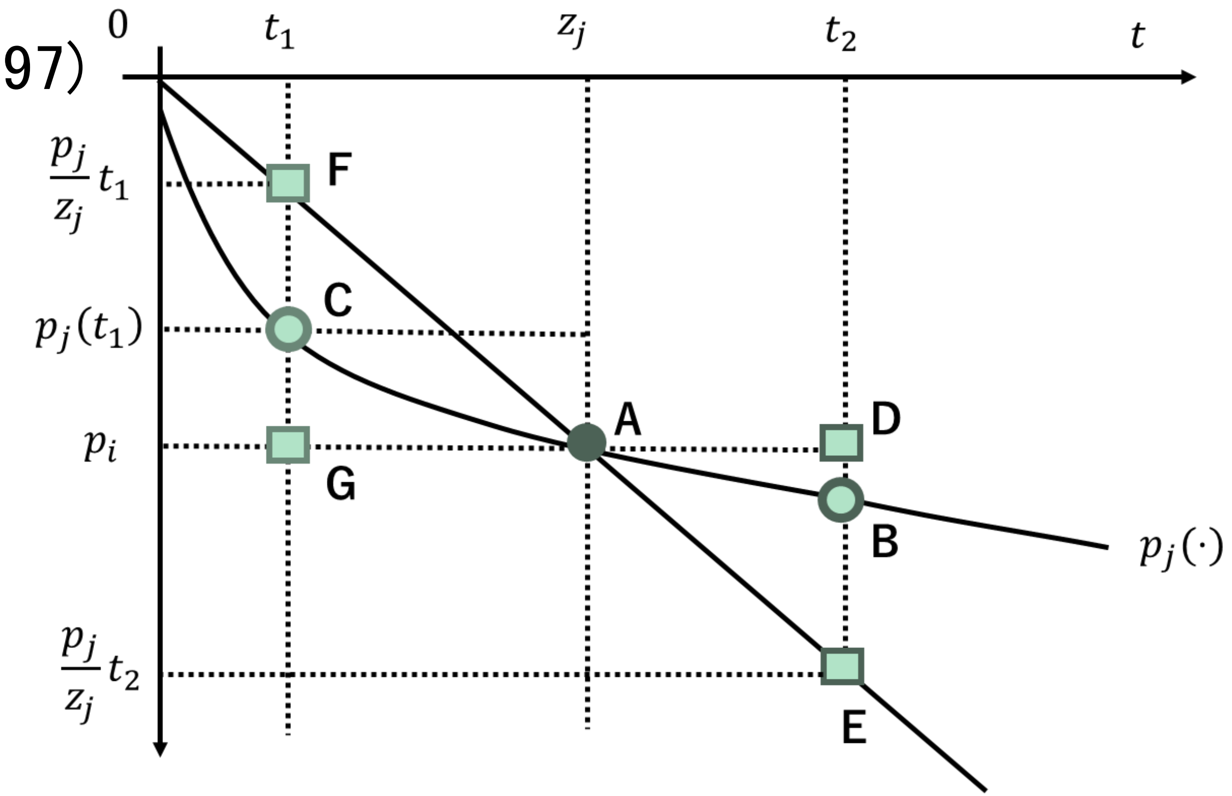
推定手法

- 部分識別
- 単調減少関数 + 操作変数：平均処置効果 ($t_2 > t_1$)

$$\left[\max_{u\in V}\left\{\sum_{t_2\le s} E[p|z=s,v=u]\Pr(z=s|v=u)+p_0\Pr(z<t_2|v=u)\right\}\right.$$
$$\left.-\min_{u\in V}\left\{p_1\Pr(z>t_1|v=u)+\sum_{s\le t_1}E[p|z=s,v=u]\Pr(z=s|v=u)\right\}\right]/(t_2-t_1)$$
$$\le\{E[p(t_2)]-E[p(t_1)]\}/(t_2-t_1)\le 0.$$

Data & Estimation Methodology

- 推定手法
  - 部分識別
  - Convex + 単調減少関数：Manski (1997)



Data & Estimation Methodology

- 推定手法
  - 部分識別
  - Convex+ 単調減少関数：Manski (1997)

$$\sum_{s\leq t} E[p|z=s]\Pr(z=s) + \sum_{s>t} E\left[\frac{p}{s}\, t \,\middle|\, z=s\right]\Pr(z=s)$$

$$\leq E[p(t)] \leq$$

$$\sum_{s<t} E\left[\frac{p}{s}\, t \,\middle|\, z=s\right]\Pr(z=s) + \sum_{s\geq t} E[p|z=s]\Pr(z=s).$$

Data & Estimation Methodology

推定手法

部分識別

Convex+ 単調減少関数:平均処置効果

$$
\Bigg[\sum_{s<t_2} E[p|z=s]\Pr(z=s) + \sum_{s\le t_2} E\left[\frac{p}{s}t_2 \,\middle|\, z=s\right]\Pr(z=s)
$$

$$
- \sum_{s\le t_1} E\left[\frac{p}{t_2}t_1 \,\middle|\, z=s\right]\Pr(z=s) + E\left[\frac{p}{s}t_1 \,\middle|\, z=s\right]\Pr(z=s)\Bigg] /(t_2-t_1)
$$

$$
\le \{E[p(t_2)] - E[p(t_1)]\}/(t_2-t_1) \le 0.
$$

Data & Estimation Methodology

推定手法

- 部分識別
- Convex + 単調減少関数 + 操作変数: 平均処置効果

$$\left[\max_{u\in V}\left\{\sum_{s<t_2} E[p|z=s,v=u]\Pr(z=s|v=u)+\sum_{s\le t_2} E\left[\frac{p}{s}t_2\,\middle|\,z=s,v=u\right]\Pr(z=s|v=u)\right\}\right.$$
$$\left.-\min_{u\in V}\left\{\sum_{s\le t_1} E\left[\frac{p}{t_2}t_1\,\middle|\,z=s,v=u\right]\Pr(z=s|v=u)+E\left[\frac{p}{s}t_1\,\middle|\,z=s,v=u\right]\Pr(z=s|v=u)\right\}\right]$$
$$/(t_2-t_1)\le\{E[p(t_2)]-E[p(t_1)]\}/(t_2-t_1)\le 0.$$

Data & Estimation Methodology

- 推定手法
  - 部分識別
  - Finite Sample Bias： Imbens and Manski (2004)、Kreider and Pepper (2007)

    操作変数などを使用する際、Bound が過少に推定される

    → Chernozhukov et al. (2013) : median-bias-corrected estimation methodology

    推定値は、普遍性 (unbiased estimator) を持つことが示されている

Results of Empirical Analysis

- 推定
  - 点推定

$$p_i = \beta_0 + \beta_1 z_i + \boldsymbol{\beta X} + \varepsilon$$

p_j: $\log CCpop_{90} - \log CCpop_{50}$、 z_j : 高速道路の本数

  - その他の変数

(i) : $\sqrt{1950\ CC\ area}$

(ii) : (i) + $\Delta \log simulated\ income$

(iii) : (ii) + $\Delta \log \mathrm{MSA\ pop.}$

(iv) : (iii) + $Gini\ coefficient$

(v) : (iii) + $\log 1950\ MSA\ pop.$

Open city model と整合的

Results of Empirical Analysis

推定

サンプル

1. すべての Metropolitan Statistical Area (MSA)　→　240都市
2. 1950年時点で中心都市の人口が 50,000人以上　→　151都市
3. 1950年時点で中心都市の人口が 75,000人以上　→　111都市
4. 1950年時点で都市圏内の人口が 100,000人以上　→　165都市
5. 2. と4. の共通部分　→　139都市

Results of Empirical Analysis

- 推定
  - 推定結果
  - 点推定

    高速道路を1本追加すると11%ほど

    中心都市の人口が減少する

	1. All MSA in 2000	2. CC pop. > 50k in 1950	3. CC pop. > 75k in 1950	4. MA pop. > 100k in 1950	5. CC pop. > 50k & MSA pop. > 100k in 1950
	Panel A: Point estimation				
(i)	-0.090***	-0.108***	-0.128***	-0.105***	-0.112***
	(-3.44)	(-3.34)	(-2.47)	(-3.10)	(-3.11)
(ii)	-0.078***	-0.113***	-0.130***	-0.098***	-0.118***
	(-3.26)	(-3.39)	(-2.63)	(-3.15)	(-3.23)
(iii)	-0.133***	-0.130***	-0.139***	-0.137***	-0.128***
	(-4.27)	(-4.03)	(-3.49)	(-3.65)	(-3.77)
(iv)	-0.131***	-0.120***	-0.125***	-0.118***	-0.117***
	(-4.41)	(-4.08)	(-3.80)	(-3.64)	(-3.99)
(v)	-0.109**	-0.099*	-0.122**	-0.122**	-0.106*
	(-2.07)	(-1.92)	(-2.13)	(-2.15)	(-1.98)
	Panel B: Bound estimation				
(vi)	[-0.328, 0]	[-0.217, 0]	[-0.260, 0]	[-0.361, 0]	[-0.239, 0]
C. I.	[-0.333, 0]	[-0.223, 0]	[-0.267, 0]	[-0.370, 0]	[-0.245, 0]
(vii)	[-0.172, 0]	[-0.088, 0]	[-0.065, 0]	[-0.145, 0]	[-0.086, 0]
C. I.	[-0.175, 0]	[-0.090, 0]	[-0.066, 0]	[-0.147, 0]	[-0.090, 0]
No. Obs.	240	151	111	165	139

Results of Empirical Analysis

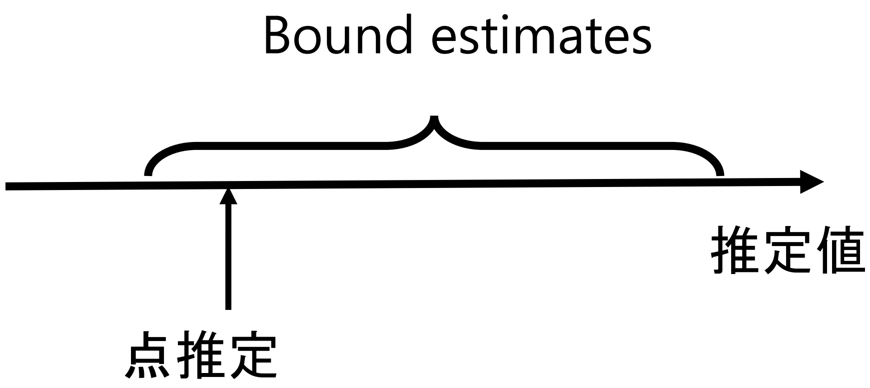
▍推定

▍推定結果

▍Bound estimation: (vi)

単調減少関数 + 操作変数

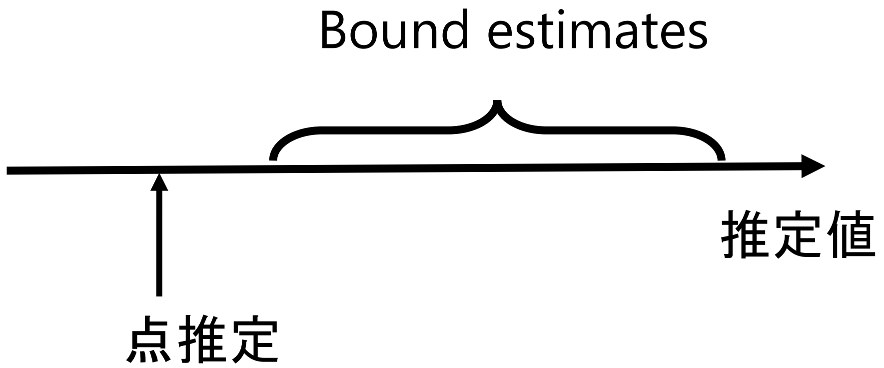
点推定値が Bound の中



	1. All MSA in 2000	2. CC pop. > 50k in 1950	3. CC pop. > 75k in 1950	4. MA pop. > 100k in 1950	5. CC pop. > 50k & MSA pop. > 100k in 1950
			Panel A: Point estimation		
(i)	-0.090***	-0.108***	-0.128***	-0.105***	-0.112***
	(-3.44)	(-3.34)	(-2.47)	(-3.10)	(-3.11)
(ii)	-0.078***	-0.113***	-0.130***	-0.098***	-0.118***
	(-3.26)	(-3.39)	(-2.63)	(-3.15)	(-3.23)
(iii)	-0.133***	-0.130***	-0.139***	-0.137***	-0.128***
	(-4.27)	(-4.03)	(-3.49)	(-3.65)	(-3.77)
(iv)	-0.131***	-0.120***	-0.125***	-0.118***	-0.117***
	(-4.41)	(-4.08)	(-3.80)	(-3.64)	(-3.99)
(v)	-0.109**	-0.099*	-0.122**	-0.122**	-0.106*
	(-2.07)	(-1.92)	(-2.13)	(-2.15)	(-1.98)
			Panel B: Bound estimation		
(vi)	[-0.328, 0]	[-0.217, 0]	[-0.260, 0]	[-0.361, 0]	[-0.239, 0]
C. I.	[-0.333, 0]	[-0.223, 0]	[-0.267, 0]	[-0.370, 0]	[-0.245, 0]
(vii)	[-0.172, 0]	[-0.088, 0]	[-0.065, 0]	[-0.145, 0]	[-0.086, 0]
C. I.	[-0.175, 0]	[-0.090, 0]	[-0.066, 0]	[-0.147, 0]	[-0.090, 0]
No. Obs.	240	151	111	165	139

Results of Empirical Analysis

- 推定
  - 推定結果
  - Bound estimation：(vii)
    Convex + 単調減少関数 + 操作変数
    2., 3., 5. のサンプルで点推定値が
    Bound の外側にある



	1. All MSA in 2000	2. CC pop. > 50k in 1950	3. CC pop. > 75k in 1950	4. MA pop. > 100k in 1950	5. CC pop. > 50k & MSA pop. > 100k in 1950
			Panel A: Point estimation		
(i)	-0.090***	-0.108***	-0.128***	-0.105***	-0.112***
	(-3.44)	(-3.34)	(-2.47)	(-3.10)	(-3.11)
(ii)	-0.078***	-0.113***	-0.130***	-0.098***	-0.118***
	(-3.26)	(-3.39)	(-2.63)	(-3.15)	(-3.23)
(iii)	-0.133***	-0.130***	-0.139***	-0.137***	-0.128***
	(-4.27)	(-4.03)	(-3.49)	(-3.65)	(-3.77)
(iv)	-0.131***	-0.120***	-0.125***	-0.118***	-0.117***
	(-4.41)	(-4.08)	(-3.80)	(-3.64)	(-3.99)
(v)	-0.109**	-0.099*	-0.122**	-0.122**	-0.106*
	(-2.07)	(-1.92)	(-2.13)	(-2.15)	(-1.98)
			Panel B: Bound estimation		
(vi)	[-0.328, 0]	[-0.217, 0]	[-0.260, 0]	[-0.361, 0]	[-0.239, 0]
C. I.	[-0.333, 0]	[-0.223, 0]	[-0.267, 0]	[-0.370, 0]	[-0.245, 0]
(vii)	[-0.172, 0]	[-0.088, 0]	[-0.065, 0]	[-0.145, 0]	[-0.086, 0]
C. I.	[-0.175, 0]	[-0.090, 0]	[-0.066, 0]	[-0.147, 0]	[-0.090, 0]
No. Obs.	240	151	111	165	139

Results of Empirical Analysis

- 推定
  - 推定結果:robustness check
  - 指標（h/p ratio）

$$z\ /pop$$

人口当たりの高速道路の本数: 小さい → 混雑している地域

大きい → 空いている地域

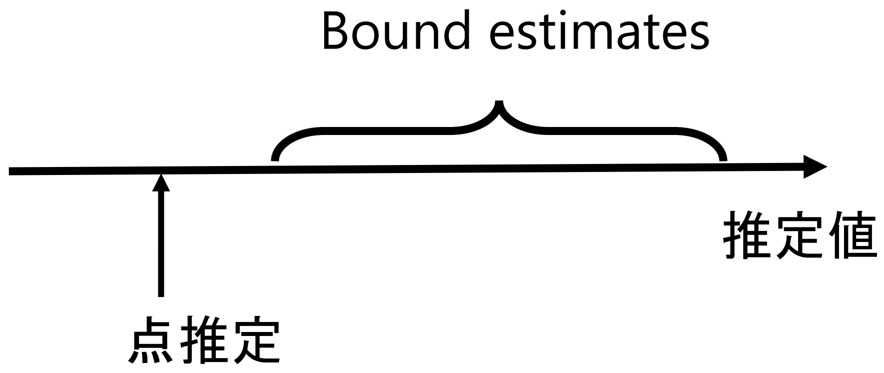
Results of Empirical Analysis

- 推定
  - 推定結果：robustness check（中心都市）
  - 混雑している地域（below median）

    点推定値 → −0.011 ～ −0.09

    Bound → −0.099 ～ 0

→ 点推定値は Bound の外側



	h/p ratio in CC		h/p ratio in MA	
	below median	below quartile	below median	below quartile
	Panel A: Point estimation			
(i)	-0.093***	-0.092***	-0.079***	-0.105***
	(-3.79)	(-4.45)	(-3.20)	(-3.60)
(ii)	-0.090***	-0.086***	-0.076***	-0.094***
	(-3.57)	(-4.05)	(-2.98)	(-3.42)
(iii)	-0.112***	-0.121***	-0.104***	-0.136***
	(-4.48)	(-5.14)	(-3.98)	(-3.93)
(iv)	-0.109***	-0.123***	-0.100***	-0.132***
	(-4.24)	(-4.99)	(-3.71)	(-4.03)
(v)	-0.113***	-0.092**	-0.107**	-0.175**
	(-3.01)	(-2.57)	(-2.43)	(-2.21)
	Panel B: Bound estimation			
(vi)	[-0.108, 0]	[-0.189, 0]	[-0.159, 0]	[-0.225, 0]
C. I.	[-0.113, 0]	[-0.194, 0]	[-0.166, 0]	[-0.229, 0]
(vii)	[-0.098, 0]	[-0.116, 0]	[-0.108, 0]	[-0.117, 0]
C. I.	[-0.099, 0]	[-0.119, 0]	[-0.110, 0]	[-0.120, 0]
No.obs	119	180	113	179

Results of Empirical Analysis

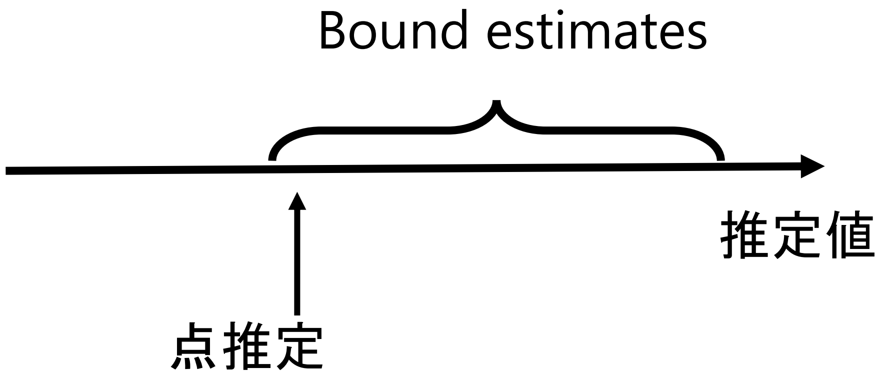
推定

- 推定結果 : robustness check (都市圏)
- 混雑している地域 (below median)

点推定値 → −0.107 〜 −0.079

Bound → −0.099 〜 0

→ 点推定値は Bound の内側



	h/p ratio in CC		h/p ratio in MA	
	below median	below quartile	below median	below quartile
	Panel A: Point estimation			
(i)	-0.093***	-0.092***	-0.079***	-0.105***
	(-3.79)	(-4.45)	(-3.20)	(-3.60)
(ii)	-0.090***	-0.086***	-0.076***	-0.094***
	(-3.57)	(-4.05)	(-2.98)	(-3.42)
(iii)	-0.112***	-0.121***	-0.104***	-0.136***
	(-4.48)	(-5.14)	(-3.98)	(-3.93)
(iv)	-0.109***	-0.123***	-0.100***	-0.132***
	(-4.24)	(-4.99)	(-3.71)	(-4.03)
(v)	-0.113***	-0.092**	-0.107**	-0.175**
	(-3.01)	(-2.57)	(-2.43)	(-2.21)
	Panel B: Bound estimation			
(vi)	[-0.108, 0]	[-0.189, 0]	[-0.159, 0]	[-0.225, 0]
C. I.	[-0.113, 0]	[-0.194, 0]	[-0.166, 0]	[-0.229, 0]
(vii)	[-0.098, 0]	[-0.116, 0]	[-0.108, 0]	[-0.117, 0]
C. I.	[-0.099, 0]	[-0.119, 0]	[-0.110, 0]	[-0.120, 0]
No.obs	119	180	113	179

Results of Empirical Analysis

推定

- Robustness check

$$p_i = \beta_0 + \beta_1 z_i + \boldsymbol{\beta X} + \varepsilon$$

- Potential endogeneity（Garcia-Lopez et al., 2015; Baum-Snow et al., 2017）

(i) : $\sqrt{1950\ CC\ area}$

(ii) : (i) + $\Delta \log simulated\ income$

(iii) : (ii) + $\Delta \log \mathrm{MSA\ pop.}$ ← Potential endogeneity

(iv) : (iii) + $Gini\ coefficient$

(v) : (iii) + $\log 1950\ MSA\ pop.$ ← Potential endogeneity

Results of Empirical Analysis

- 推定
  - Robustness check
  - Potential endogeneity

$\Delta \log MSA\ pop$

操作変数を使用 (Garcia-Lopez et al., 2015)

国内の人口増加 － 該当の都市圏の人口増加

$\log 1950\ MSA\ pop$

1940年の都市圏内の人口を代わりに用いる

Results of Empirical Analysis

推定

Robustness check

$$p_j = \beta_0 + \beta_1 z_j + \boldsymbol{\beta X} + \varepsilon_j$$

その他の変数：（ii）$\sqrt{1950\ CC\ area} + \Delta \log simulated\ income$

- viii. : (ii) + $\Delta \log \mathrm{MSA\ pop.}$
- ix. : (ii) + $Gini\ coefficient + \Delta \log \mathrm{MSA\ pop.}$
- x. : (ii) + $Gini\ coefficient + \Delta \log \mathrm{MSA\ pop.} + \log 1950\ MSA\ pop.$
- xi. : (ii) + $Gini\ coefficient + \Delta \log \mathrm{MSA\ pop.} + \log 1940\ MSA\ pop.$
- xii. : (ii) + $Gini\ coefficient + \Delta \log \mathrm{MSA\ pop.} + \log 1940\ MSA\ pop.$

Results of Empirical Analysis

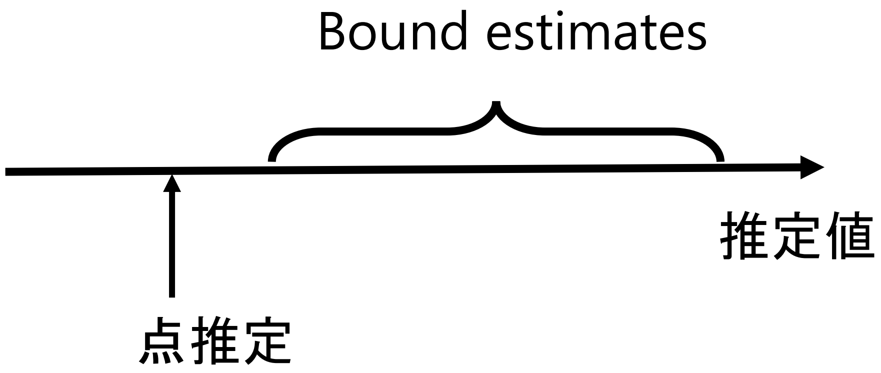
推定

- 推定結果：Robustness Check
- Potential endogeneity

結果はメインのものと変わらず

2., 3., 5. のサンプルで点推定値が

Bound の外側にある



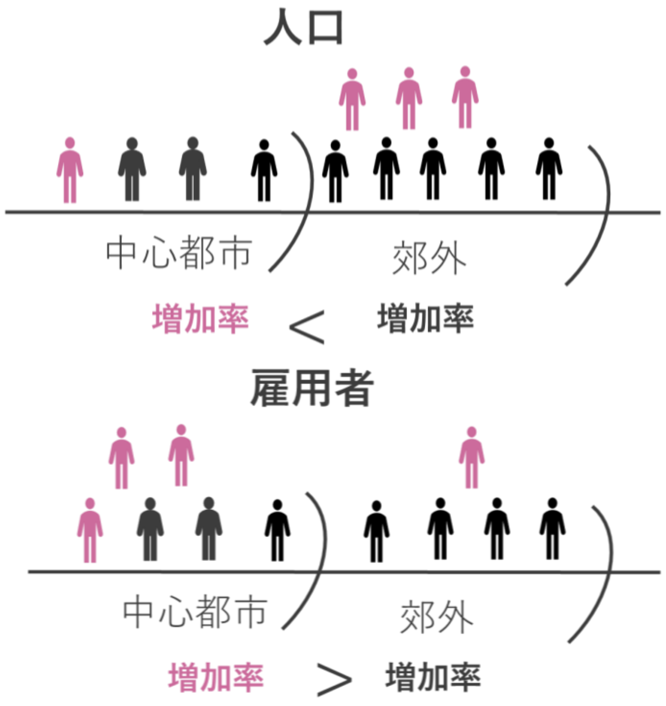
	1. All MSA in 2000	2. CC pop. > 50k in 1950	3. CC pop. > 75k in 1950	4. MA pop. > 100k in 1950	5. CC pop. > 50k & MA pop. > 100k in 1950
	Panel A: Point estimation				
(viii)	-0.138***	-0.133***	-0.140***	-0.142***	-0.131***
	(-4.26)	(-4.17)	(-3.58)	(-3.81)	(-3.89)
(ix)	-0.136***	-0.127***	-0.129***	-0.129***	-0.127***
	(-4.39)	(-4.32)	(-3.95)	(-3.99)	(-4.17)
(x)	-0.113*	-0.099*	-0.122**	-0.127**	-0.107*
	(-1.85)	(-1.89)	(-2.10)	(-2.13)	(-2.01)
(xi)	-0.107**	-0.095*	-0.117*	-0.115**	-0.103*
	(-2.04)	(-1.70)	(-1.81)	(-2.05)	(-1.83)
(xii)	-0.113*	-0.093*	-0.117*	-0.121*	-0.099*
	(-1.72)	(-1.82)	(-1.96)	(-1.96)	(-1.85)
	Panel B: Bound estimation				
(vi)	[-0.328, 0]	[-0.217, 0]	[-0.260, 0]	[-0.361, 0]	[-0.239, 0]
C. I.	[-0.333, 0]	[-0.223, 0]	[-0.267, 0]	[-0.370, 0]	[-0.245, 0]
(vii)	[-0.172, 0]	[-0.088, 0]	[-0.065, 0]	[-0.145, 0]	[-0.086, 0]
C. I.	[-0.175, 0]	[-0.090, 0]	[-0.066, 0]	[-0.147, 0]	[-0.090, 0]
No. Obs.	240	151	111	165	139

Conclusion

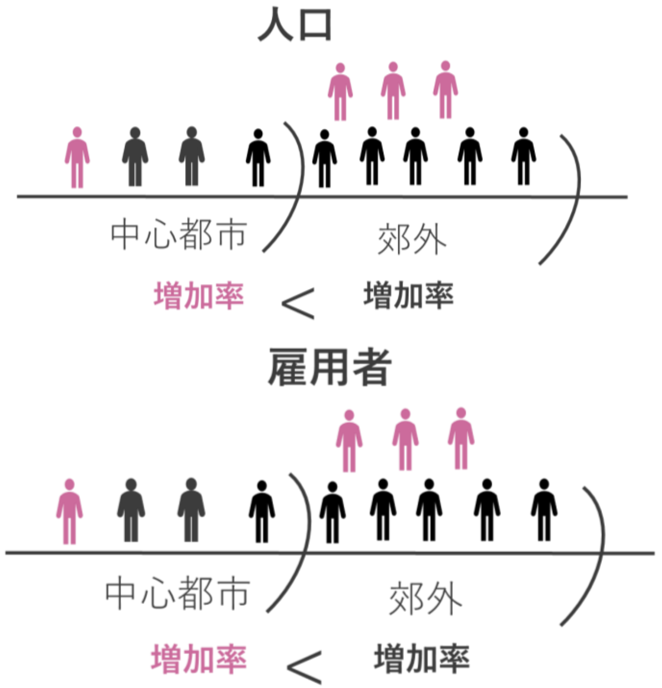
結論

目的:郊外化のメカニズムの解明

Canonical Urban Model
インフラの整備 → 通勤費用の低下 → 郊外化



提案モデル
交通インフラの整備 → 混雑の増加 → 郊外化

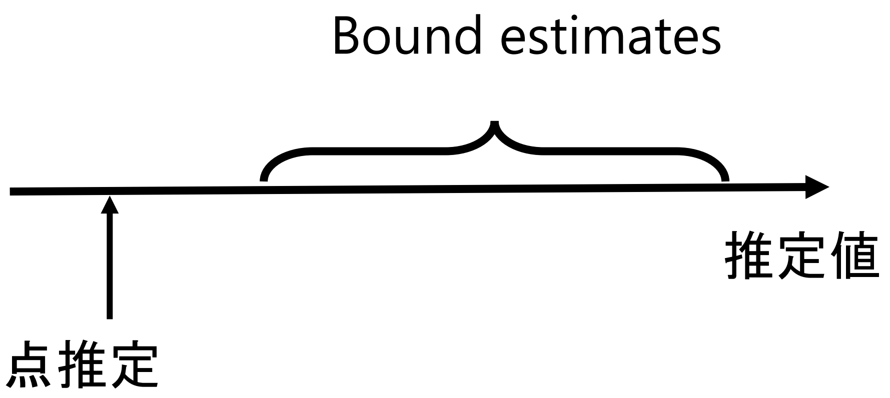


Conclusion

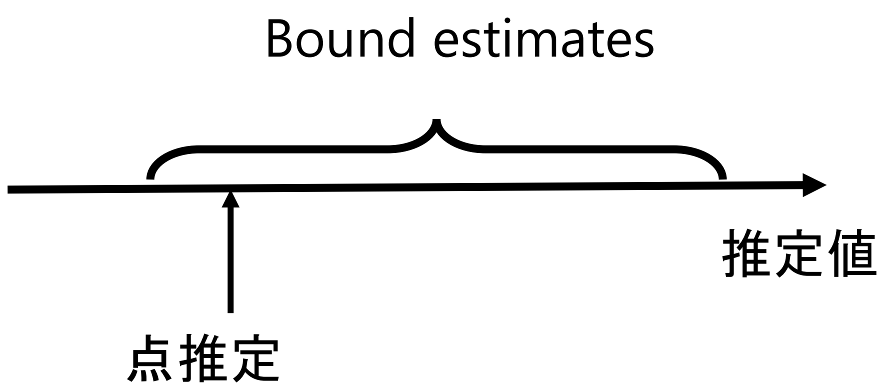
結論

- 推定結果:1950年時点で中心都市の人口が多い都市のデータを使用

Canonical Urban Model



混雑入りモデル



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