Carpooling and Congestion Pricing:

HOV and HOT Lanes

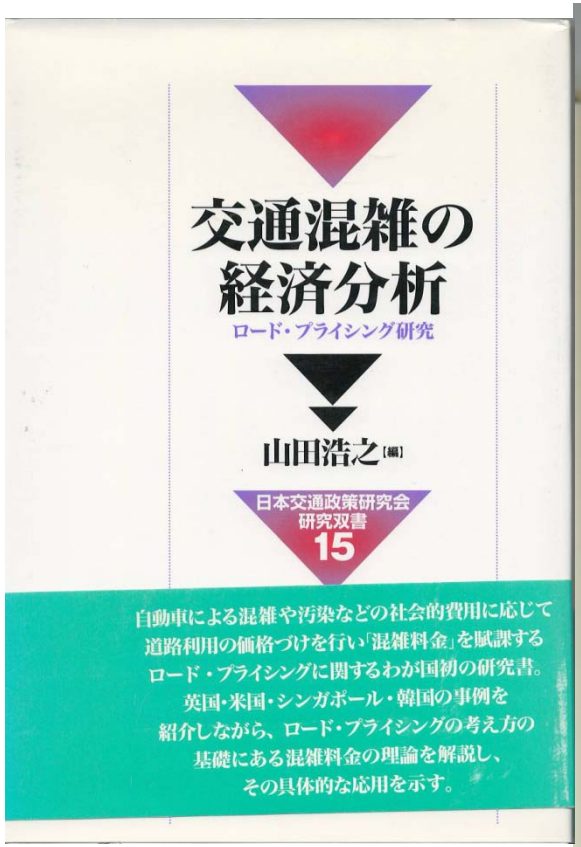
Hideo Konishi (Boston College)

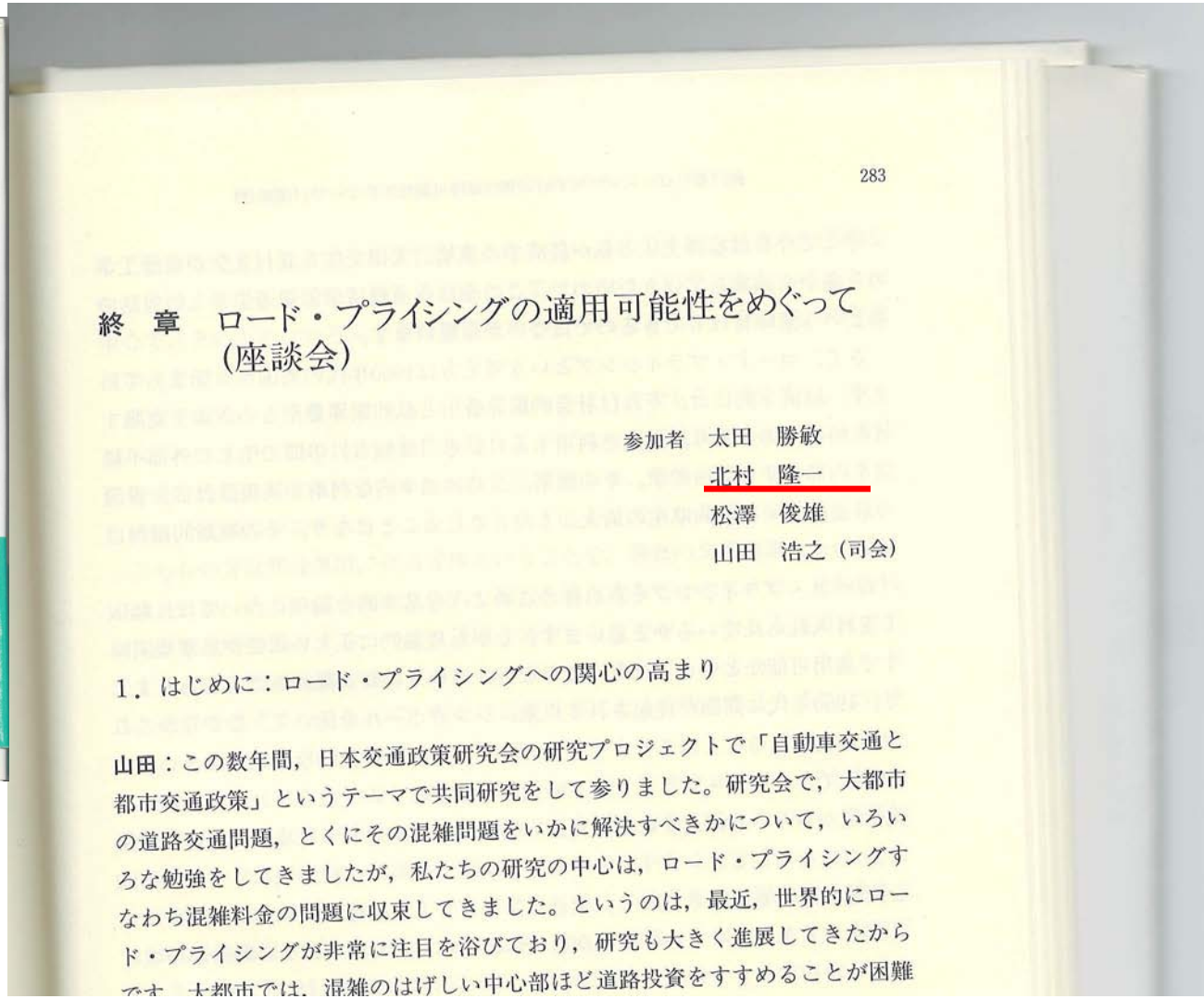
and

Se-il Mun (Kyoto University)

Paper is available at
http://www.econ.kyoto-u.ac.jp/~mun/papers/hovhot2010209withfigures.pdf

Prof. Kitamura inspired us to do this work (not consciously)





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終　章　ロード・プライシングの適用可能性をめぐって
(座談会)

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1．はじめに：ロード・プライシングへの関心の高まり

山田：この数年間，日本交通政策研究会の研究プロジェクトで「自動車交通と都市交通政策」というテーマで共同研究をして参りました。研究会で，大都市の道路交通問題，とくにその混雑問題をいかに解決すべきかについて，いろいろな勉強をしてきましたが，私たちの研究の中心は，ロード・プライシングすなわち混雑料金の問題に収束してきました。というのは，最近，世界的にロード・プライシングが非常に注目を浴びており，研究も大きく進展してきたからです。大都市では，混雑のはげしい中心部ほど道路投資をすすめることが困難

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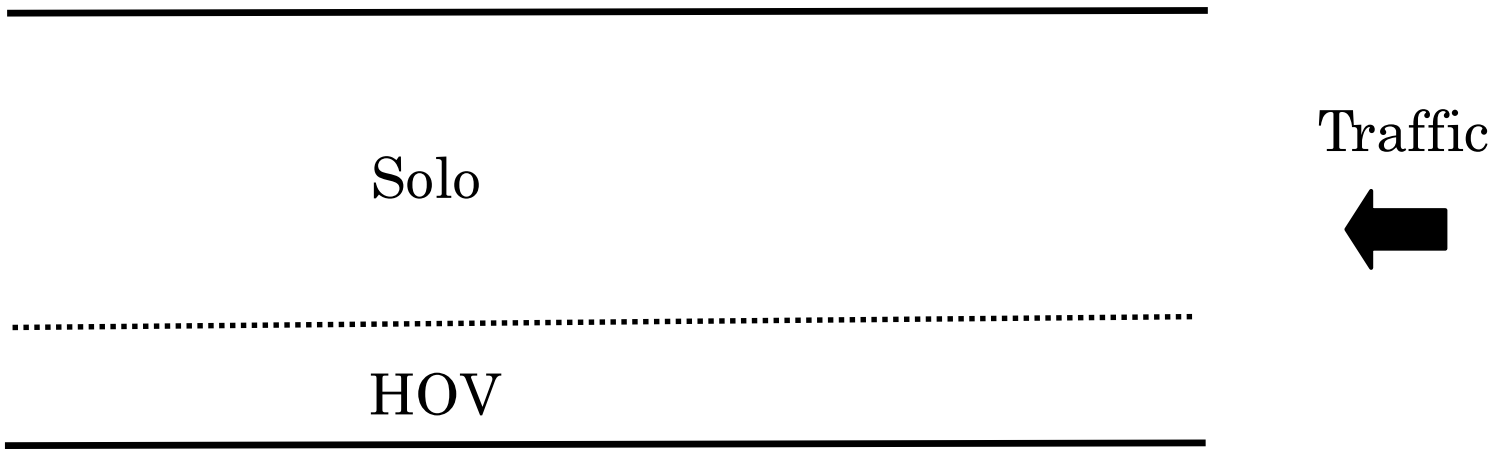
Road pricing affect travel behavior

- Trip generation
- Trip length (destination choice)
- Modal choice
- Route choice
- Departure time

- HOV or solo (Our paper)

HOV lanes – High Occupancy Vehicle lanes

- HOV lanes – reserved for high occupancy vehicles only
- regular lanes – for solo cars – will be more crowded
- incentives for carpooling – total number of cars on road is reduced



Why do we care?

- In the US (US Census Bureau, 2000),
  - 77% of commuters are solo drivers
  - 4.7% use mass transit
  - 12.2% are carpoolers (important!)

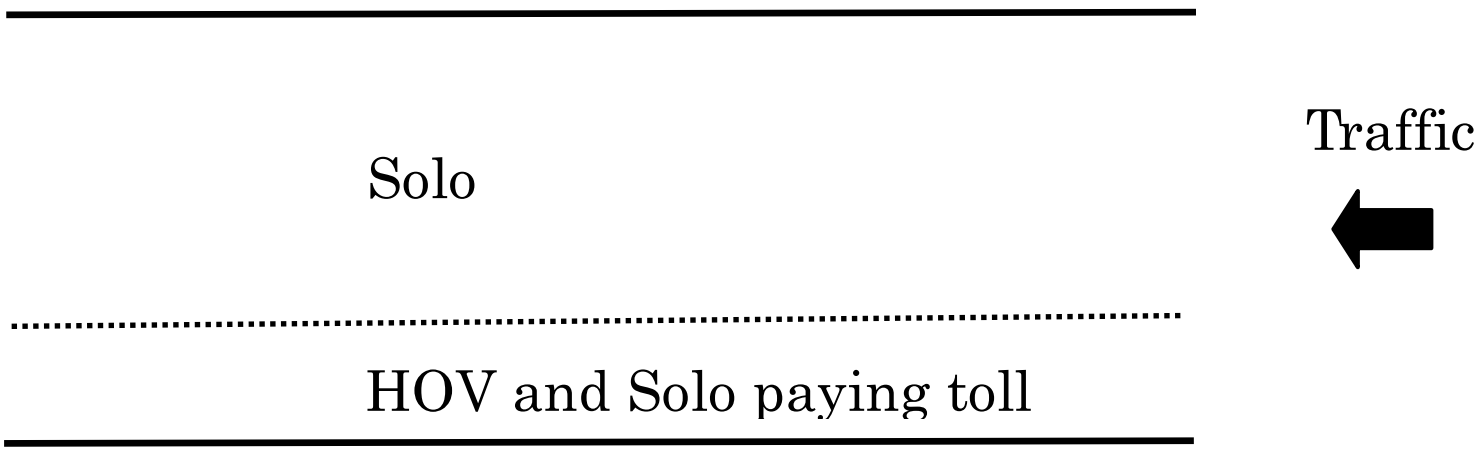
- Criticisms

- HOV lanes are underused --- likely to increase the social cost
- 43% of carpoolers are family members
- HOV lanes shift travelers from vanpools to carpools

HOT lanes

High Occupancy Toll lanes

- HOV lanes are open to HOVs for free,
  and to solo cars if tolls are paid.



High Occupancy Toll (HOT) lanes

- Supported by the US *Value Pricing Pilot Program* for innovative road and parking pricing measures for alleviating congestion (http://www.valuepricing.org)
  - traffic of regular lanes is eased (HOV lanes are underused)
  - revenue is generated
  - politically feasible policy
  - but incentives for carpooling are weakened
- Six operating facilities to date:

  State Route 91 in Riverside County, California

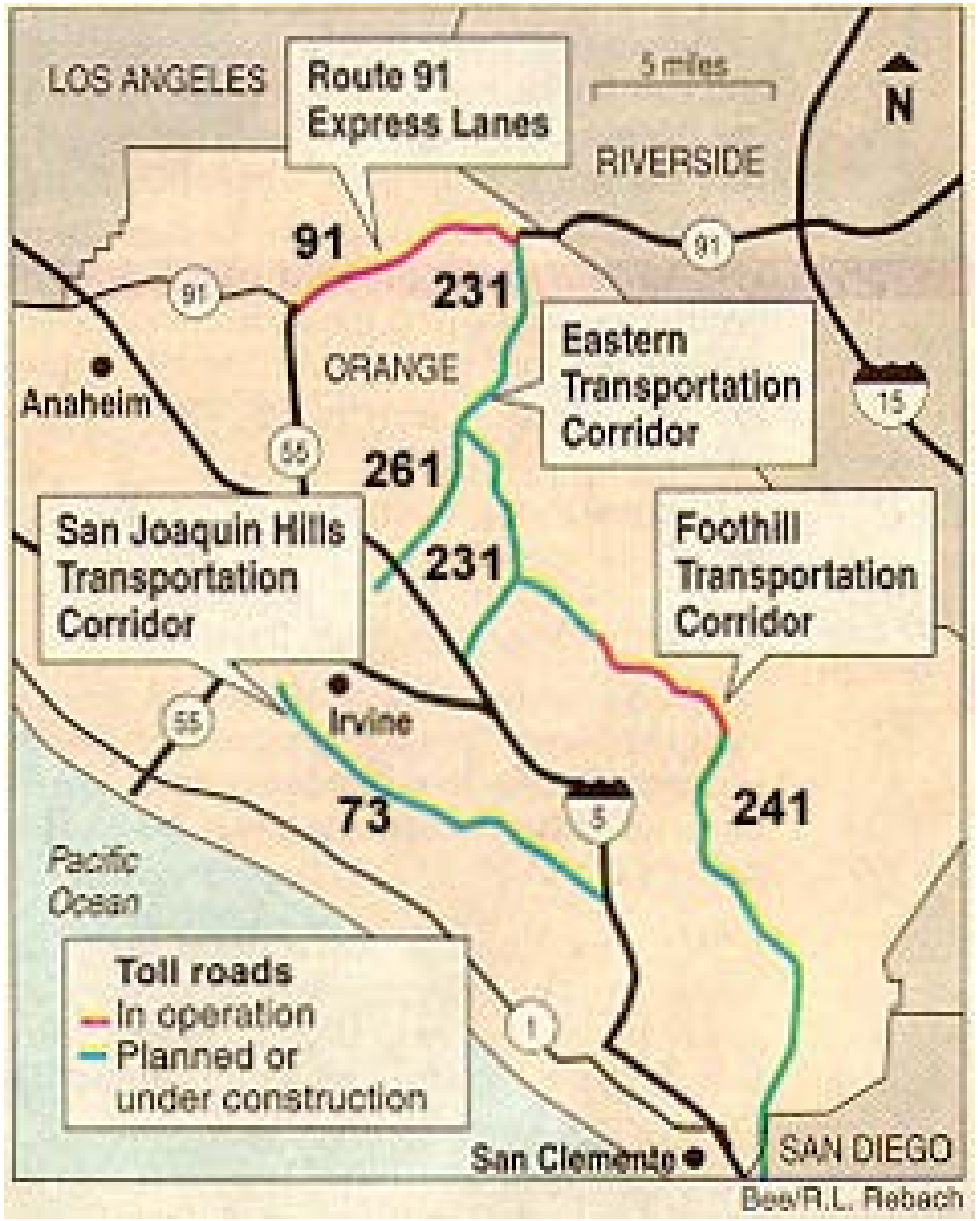
  Interstate 15 (I-15) north of San Diego

  Katy and Northwest Freeways in Houston, Texas

  Interstate 394 (I-394) in Minneapolis

  Interstate 25 (I-25) in Colorado

State Route 91, California



State Route 91, California

http://www.91expresslanes.com

State Route 91, California

Toll structure

- According to timetable. Tolls change hourly with different schedules for each day of the week →
- HOV3+ can use toll lanes free except at peak times (50% discount)

Tolling technology

- Smartcards with pre-purchased credit
- Enforcement: cameras to photograph license plates

State Route 91, California

91 Express Lanes **Toll Schedule** — Effective April 1, 2007 — **Eastbound** SR-55 to Riverside Co. Line

	Sun	M	Tu	W	Th	F	Sat
Midnight	1.15	1.15	1.15	1.15	1.15	1.15	1.15
1:00 am	1.15	1.15	1.15	1.15	1.15	1.15	1.15
2:00 am	1.15	1.15	1.15	1.15	1.15	1.15	1.15
3:00 am	1.15	1.15	1.15	1.15	1.15	1.15	1.15
4:00 am	1.15	1.15	1.15	1.15	1.15	1.15	1.15
5:00 am	1.15	1.15	1.15	1.15	1.15	1.15	1.15
6:00 am	1.15	1.85	1.85	1.85	1.85	1.85	1.15
7:00 am	1.15	1.85	1.85	1.85	1.85	1.85	1.15
8:00 am	1.50	1.85	1.85	1.85	1.85	1.85	1.85
9:00 am	1.50	1.85	1.85	1.85	1.85	1.85	1.85
10:00 am	2.30	1.85	1.85	1.85	1.85	1.85	2.30
11:00 am	2.30	1.85	1.85	1.85	1.85	1.85	2.30
Noon	2.70	1.85	1.85	1.85	1.85	2.80	2.70
1:00 pm	2.70	2.55	2.55	2.55	2.80	4.35	2.70
2:00 pm	2.70	3.70	3.70	3.70	3.80	4.35	2.70
3:00 pm	2.30	3.95	3.95	4.95	4.95	9.25	2.70
4:00 pm	2.30	6.65	8.00	8.50	9.25	9.50	2.70
5:00 pm	2.30	6.65	8.50	8.50	9.25	8.00	2.70
6:00 pm	2.30	3.95	5.45	4.95	5.75	4.75	2.30
7:00 pm	2.30	2.80	2.80	2.80	4.00	4.40	1.85
8:00 pm	2.30	1.85	1.85	1.85	2.55	4.00	1.85
9:00 pm	1.85	1.85	1.85	1.85	1.85	2.55	1.85
10:00 pm	1.15	1.15	1.15	1.15	1.15	1.85	1.15
11:00 pm	1.15	1.15	1.15	1.15	1.15	1.15	1.15

91 Express Lanes **Toll Schedule** — Effective April 1, 2007 — **Westbound** Riverside Co. Line to SR-55

	Sun	M	Tu	W	Th	F	Sat
Midnight	1.15	1.15	1.15	1.15	1.15	1.15	1.15
1:00 am	1.15	1.15	1.15	1.15	1.15	1.15	1.15
2:00 am	1.15	1.15	1.15	1.15	1.15	1.15	1.15
3:00 am	1.15	1.15	1.15	1.15	1.15	1.15	1.15
4:00 am	1.15	2.20	2.20	2.20	2.20	2.20	1.15
5:00 am	1.15	3.60	3.60	3.60	3.60	3.45	1.15
6:00 am	1.15	3.70	3.70	3.70	3.70	3.60	1.15
7:00 am	1.15	4.05	4.05	4.05	4.05	3.95	1.60
8:00 am	1.60	3.70	3.70	3.70	3.70	3.60	1.85
9:00 am	1.60	2.95	2.95	2.95	2.95	2.95	2.30
10:00 am	2.30	1.85	1.85	1.85	1.85	1.85	2.30
11:00 am	2.30	1.85	1.85	1.85	1.85	1.85	2.60
Noon	2.30	1.85	1.85	1.85	1.85	1.85	2.60
1:00 pm	2.60	1.85	1.85	1.85	1.85	1.85	2.60
2:00 pm	2.60	1.85	1.85	1.85	1.85	1.85	2.60
3:00 pm	2.60	1.85	1.85	1.85	1.85	2.30	2.60
4:00 pm	2.75	1.85	1.85	1.85	1.85	2.30	2.75
5:00 pm	2.75	1.85	1.85	1.85	1.85	2.30	2.75
6:00 pm	2.75	1.85	1.85	1.85	1.85	2.70	2.30
7:00 pm	2.30	1.15	1.15	1.15	1.15	1.85	1.85
8:00 pm	2.30	1.15	1.15	1.15	1.15	1.15	1.15
9:00 pm	2.30	1.15	1.15	1.15	1.15	1.15	1.15
10:00 pm	1.15	1.15	1.15	1.15	1.15	1.15	1.15
11:00 pm	1.15	1.15	1.15	1.15	1.15	1.15	1.15

Our paper

We use a simple model to compare the following five policies

1. regular lanes only
2. HOV lanes
   - Is introducing HOV lanes social-cost reducing?
3. HOT lanes
   - Is converting HOV lanes to HOT lanes social-cost reducing?
4. uniform congestion pricing (evey car pays the same toll)
   - Conventional policy along the line of Pigou, but is it superior to other policies?
5. differential congestion pricing with HOV lanes (HOV/HOT lanes + regular lane toll)
   - Optimal policy under lane division.

Earlier works

- Yang and Huang (1999)

  - fixed cost for carpooling

  - not considered HOT policy

- Small et al (2006), Safirova, et al (2004)

  - numerical simulations based on discrete choice models

  - welfare effects are generally unknown

The Model

- All commuters must commute from the suburb to the CBD via a highway
- unit mass of commuters
- Commuters differ in their carpooling organization costs $t \in [0,1]$
- Distribution function of is $F(t)$ for [0,1]
  with $F(0) = 0$ and $\lim_{t \to 1} F(t) = 1$
  Density function: $f(t)$
- Highway lanes can be divided into two groups, α and β
  $K_\alpha + K_\beta = 1,$ where K_i is capacity of lanes
- Commuters sort over two groups of lanes (if lanes are divided): $n_\alpha + n_\beta = 1$

- Congestion cost , ,

  $C(q) \geq 0$, $C'(q) \geq 0$, and $C''(q) \geq 0$ for all

  where is the number of cars in type lanes

- a type commuter's total cost by using type lane

  $C(q_i) + t + \tau_i$, if carpooling

  $C(q_i) + \tau_i$, if driving solo

  where τ_i is toll of type lanes

Regular Lanes only (No policy)

- No lane distinction, no toll
- There is no incentive for carpooling
  - if carpooled, then $C(\cdot)+t$
  - if solo, then $C(\cdot)$
- Thus, every lane has per lane traffic 1 – everybody pays $C(1)$

HOV Lanes

- α lanes are HOV lanes (with m commuters in a car), while β lanes are regular lanes
- no toll
- If type $\bar{t}$ is indifferent between α and β lanes, then commuters with $t \le \bar{t}$ use α lanes and the ones $t > \bar{t}$ use β lanes
- Thus, $q_\alpha = \frac{Q_\alpha}{K_\alpha} = \frac{F(\bar{t})/m}{K_\alpha}$ and $q_\beta = \frac{1-F(\bar{t})}{K_\beta}$
- Type $\bar{t}$ is indifferent

$$C(q_\alpha) + \bar{t} = C\left(\frac{F(\bar{t})}{mK_\alpha}\right) + \bar{t} = C\left(\frac{1-F(\bar{t})}{K_\beta}\right) = C(q_\beta)$$

- Equilibrium solution: $\bar{t}^{HOV}$

HOT lanes

- Lane α

  n_α^{cp} carpoolers $(= F(\bar{t}^{HOT}))$

  n_α^{s} solo drivers paying toll$(= \tau)$

- Lane β

  $1 - n_\alpha^{cp} - n_\alpha^{s}$ solo drivers

Equilibrium conditions with HOT lanes

- HOV user $\bar{t}^{HOT}$ is indifferent between HOT and regular lanes

$$C\left(\frac{F\left(\bar{t}^{HOT}\right)}{mK_\alpha}+\frac{n_\alpha^s}{K_\alpha}\right)+\bar{t}^{HOT}=C\left(\frac{1-F\left(\bar{t}^{HOT}\right)-n_\alpha^s}{K_\beta}\right)$$

- Solo drivers are indifferent between HOT lanes with paying toll and regular lanes

$$C\left(\frac{F\left(\bar{t}^{HOT}\right)}{mK_\alpha}+\frac{n_\alpha^s}{K_\alpha}\right)+\tau=C\left(\frac{1-F\left(\bar{t}^{HOT}\right)-n_\alpha^s}{K_\beta}\right)$$

- Thus, we have

$$\bar{t}^{HOT}=\tau.$$

- Equilibrium under HOT is obtained by solving

$$C\left(\frac{F(\tau)}{mK_\alpha}+\frac{n_\alpha^s}{K_\alpha}\right)+\tau=C\left(\frac{1-F(\tau)-n_\alpha^s}{K_\beta}\right)$$

for n_α^s

Is converting HOV lanes to HOT lanes cost-reducing?

- If toll is very high, no solo car uses HOT lanes.
- Solo car users use HOT lanes if toll rate τ is less than the critical value $\bar{t}^{HOV}$, where $\bar{t}^{HOV}$ is the indifferent type between two types of lanes before HOV lanes are converted to HOT lanes.
- A sufficient condition to check if HOT conversion is social cost-reducing is to check if social cost would be reduced by reducing toll rate τ from $\bar{t}^{HOV}$ slightly.

The aggregate social cost with HOT lanes

Comparing policies: A Special Case

- $F(t) = t$ uniform distribution over $[0,1]$.
- $C(q) = cq$ constant marginal congestion cost

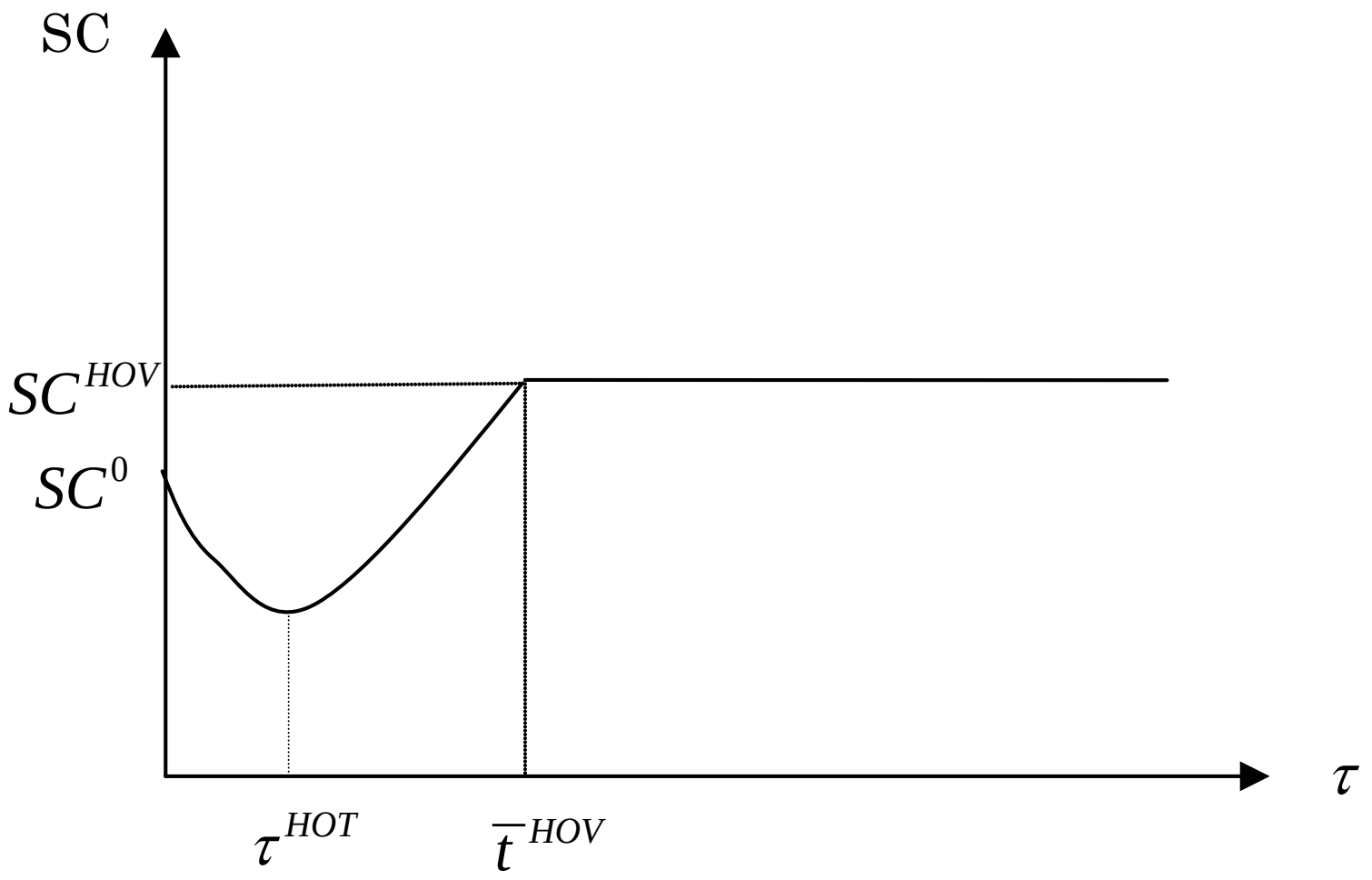


Fig.1A: Social cost may be reduced by converting HOV lane to HOT lane. Introducing HOV lane increases the social cost, i.e., $SC^{HOV} > SC^{0}$

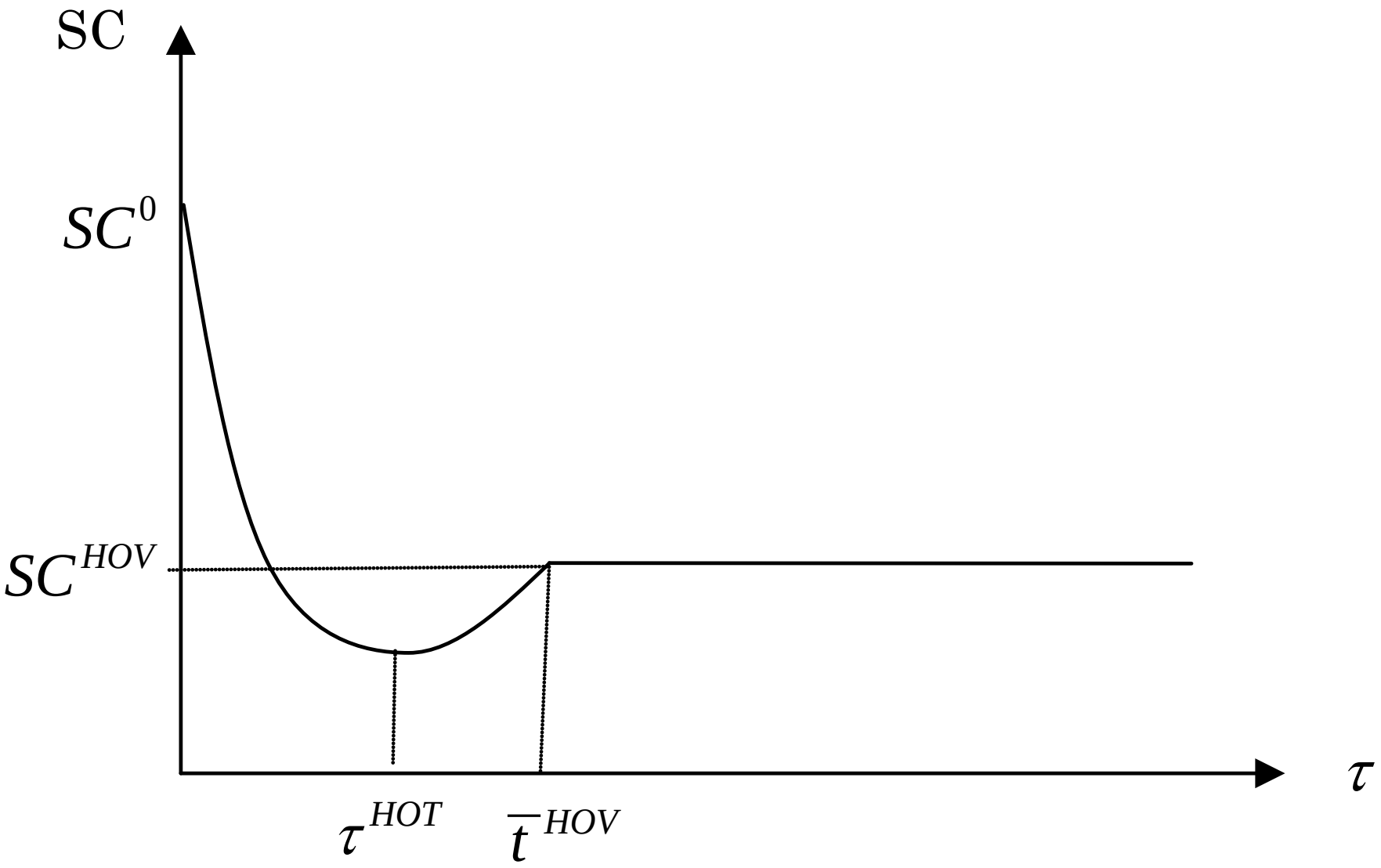


Fig.1B: Social cost may be reduced by converting HOV lane to HOT lane. Introducing HOV lane reduces the social cost, i.e., $SC^{HOV} < SC^0$

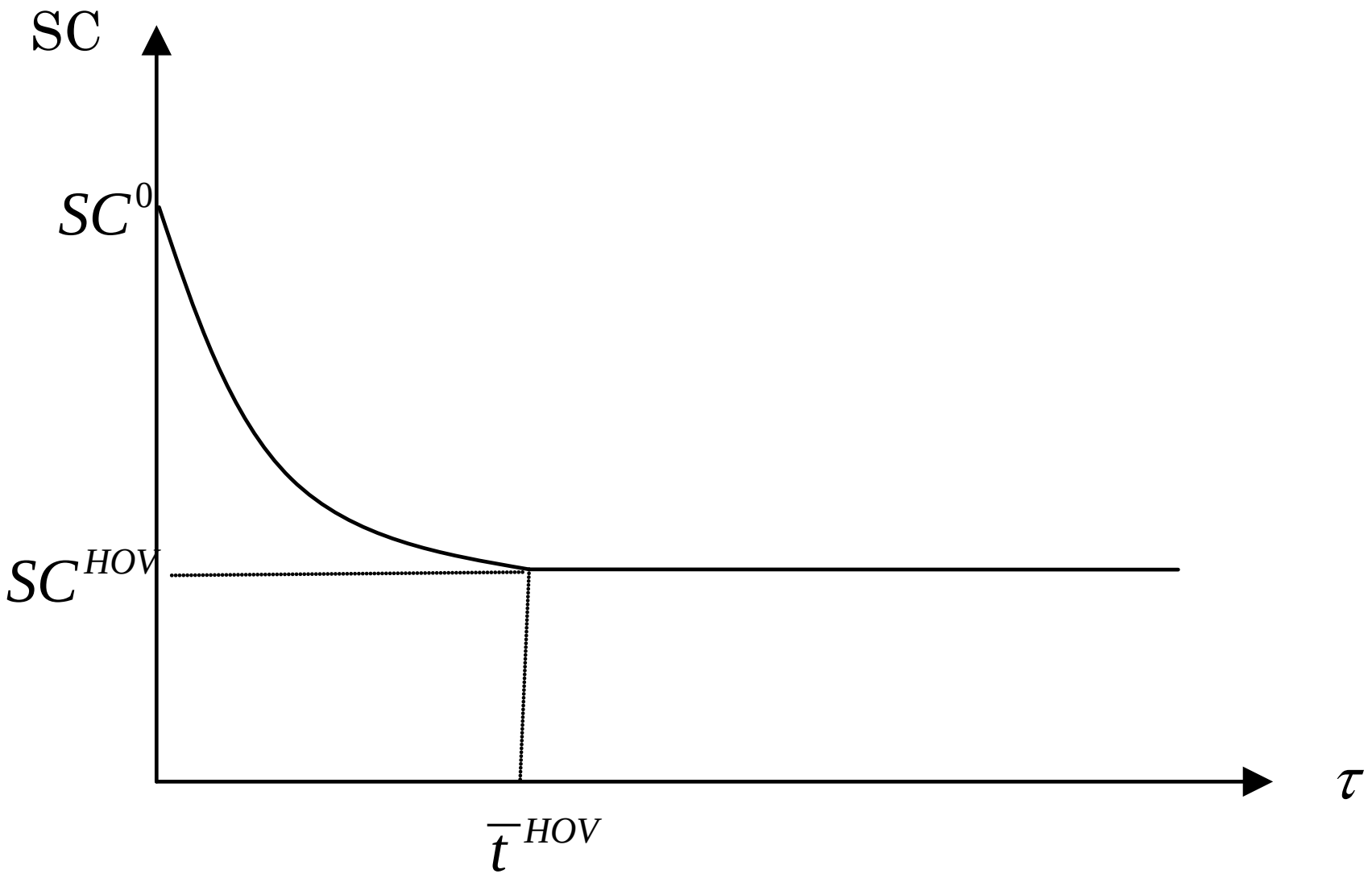
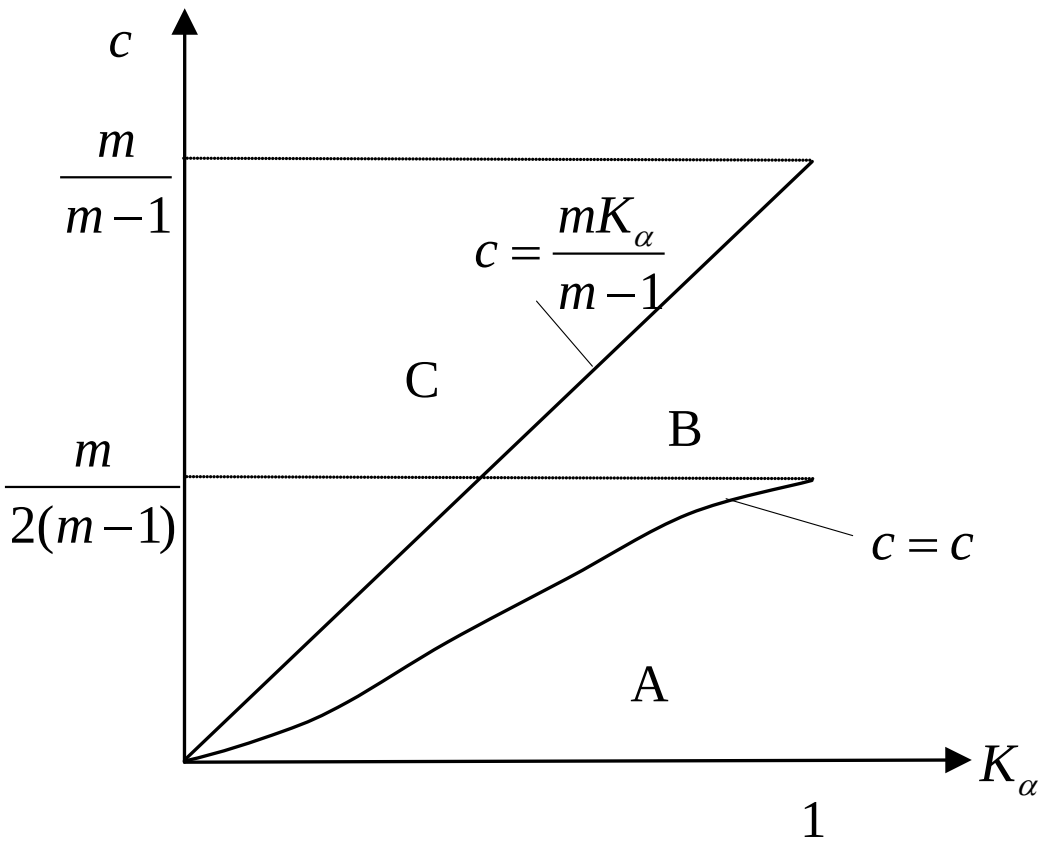


Fig.1C: Converting HOV lane to HOT lane increases the social cost.

Introducing HOV lane reduces the social cost, i.e., $SC^{HOV} < SC^0$



A: (HOT) (no policy) (HOV)

B: (HOT) (HOV) (no policy)

C: (HOV)__(HOT) (no policy)

Figure 2 Parameters and welfare ranking of HOV and HOT

Welfare-ranking of “no policy”, “HOV lanes”, and “HOT lanes ” dependent on parameter values of K_α and c.

- If K_α is very high relative to c, then

  $(HOT) \quad (no\ policy) \quad (HOV)$

- If K_α is moderately high relative to c, then

  $(HOT) \quad (HOV) \quad (no\ policy)$

- If K_α is not high relative to c, then

  $(HOV)\_(HOT) \quad (no\ policy)$

Alternative Pricing Policies

- Uniform Congestion Pricing(UCP)
  - no lane division, all vehicles pay

- Differential Congestion Pricing(DCP)
  - Carpoolers:free
  - Solo on α lanes pay τ_α
  - Solo on β lanes pay τ_β

Welfare Ranking among Alternative Policies

- Same specifications
  $F(t) = t$, $C(q) = cq$
- and $K_\alpha = 0.2$ (1 of 5 lanes)
  (Share of car-pooling =0.130)

- Social cost under alternative policies for each value of
  HOV
  HOT
  Uniform pricing
  Differential pricing

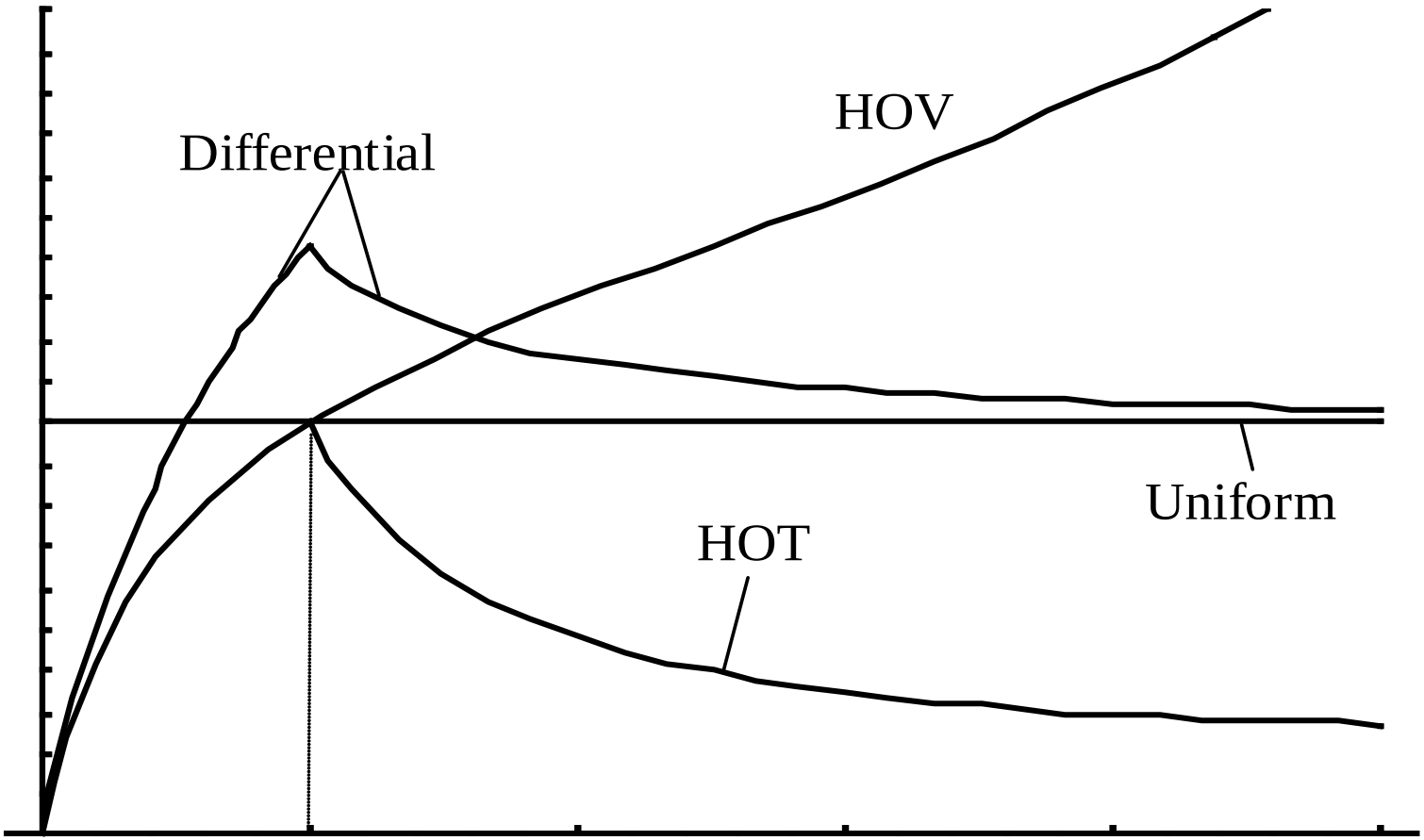


Figure 3 Shares of car-poolers under alternative policies

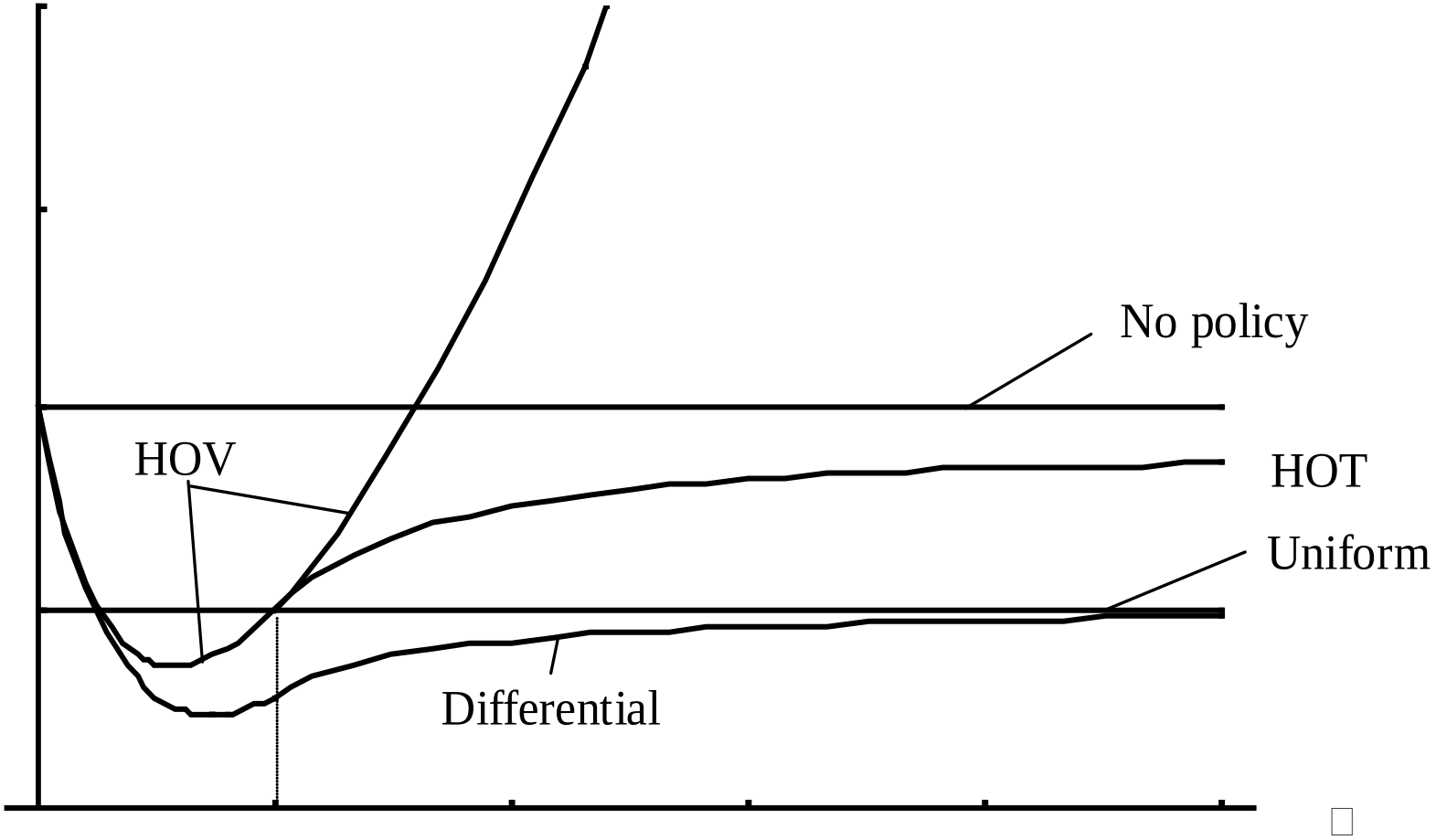


Figure 4 Aggregate social costs under alternative policies

Summary

- One of the simplest possible models
- HOV can be better or worse than no policy
- HOT can be better or worse than HOV
- Uniform pricing is not necessarily good:
  can be dominated by HOV
- DCP attains the first-best outcome:
  unlike HOT, toll should be charged on regular lanes