# *Dedicated lanes, tolls and ITS technology*

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**The Future for Interurban Passenger Transport**
**Bringing Citizens Closer Together**

**SESSION 4: TRANSPORT SYSTEM INTERACTIONS AND INNOVATION**

# Outline

1. **Overview**
2. Modeling results

# Potential advantages of vehicle separation

**Alleviate congestion**

**Enhance safety**

Enhance air quality, reduce noise

Economize on road construction & maintenance costs

Facilitate use of Long Combination Vehicles

# Constraints on vehicle separation

**Lane capacity indivisibilities**

Lack of continuous right-of-way

Limited access may increase total travel distance

Complete separation impractical or infeasible

Lane weaving

# Outline

1. Overview
2. **Modeling results**

# Scope of model

De Palma, A., M. Kilani and R. Lindsey (2008), "The merits of separating cars and trucks", Journal of Urban Economics 64(2), 340–361.

Analytical

## Infrastructure

Fixed

## Driver choices

Route (or lane)

## Regulatory regimes

Unregulated user equilibrium

Tolls: comprehensive, partial

Route (or lane) access restrictions

System optimum

## Externalities

Congestion, accidents; pollution, noise, road damage

# Model

*Trip matrix*: One origin-destination pair

*Routes*: $r = 1, 2$. Perfect substitutes

*Route capacities*: Fixed

*Demand*:

Types: *Lights* and *Heavies*

Inelastic volumes: $N_L$ , $N_H$

*Route allocation*:

$$N_{L1} + N_{L2} = N_L$$

$$N_{H1} + N_{H2} = N_H$$

# Model (cont.)

*Private trip costs*

$$C_r^L = F_r^L + c_{Lr}^L N_{Lr} + c_{Hr}^L N_{Hr} + \tau_r^L, \quad r = 1, 2$$

$$C_r^H = F_r^H + c_{Lr}^H N_{Lr} + c_{Hr}^H N_{Hr} + \tau_r^H, \quad r = 1, 2$$

Own-cost coefficients: $c_{Lr}^L, \ c_{Hr}^H, \quad r = 1, 2$

Cross-cost coefficients: $c_{Hr}^L, \ c_{Lr}^H, \quad r = 1, 2$

# Unregulated equilibrium (UE)

*Types of equilibrium route allocations*

1. Integrated
2. Partially separated
3. Segregated (fully separated)

7 possible configurations. 56 toll combinations.

Equilibrium depends on:

- Relative numbers $(N_L, N_H)$
- Relative capacities of the routes

Necessary condition for integrated UE:

$$\left(c_{L1}^{L}+c_{L2}^{L}\right)\left(c_{H1}^{H}+c_{H2}^{H}\right)>\left(c_{H1}^{L}+c_{H2}^{L}\right)\left(c_{L1}^{H}+c_{L2}^{H}\right)$$

$$\text{or}\quad c_{L\bullet}^{L}c_{H\bullet}^{H}>c_{H\bullet}^{L}c_{L\bullet}^{H}$$

# System optimum (SO)

*Average system trip costs*

$$ASC_r^L = F_r^L + c_{Lr}^L N_{Lr} + c_{Hr}^L N_{Hr} + e_{Lr}, \quad r = 1, 2$$

$$ASC_r^H = F_r^H + c_{Lr}^H N_{Lr} + c_{Hr}^H N_{Hr} + e_{Hr}, \quad r = 1, 2$$

*Marginal system trip costs*

$$MSC_r^L = \left(C_r^L - \tau_r^L\right) + \underbrace{c_{Lr}^L N_{Lr}}_{Own} + \underbrace{c_{Lr}^H N_{Hr}}_{Cross} + \underbrace{e_{Lr}}_{Environ.}, \quad r = 1, 2$$

$$MSC_r^H = \left(C_r^H - \tau_r^H\right) + \underbrace{c_{Hr}^H N_{Hr}}_{Own} + \underbrace{c_{Hr}^L N_{Lr}}_{Cross} + \underbrace{e_{Hr}}_{Environ.}, \quad r = 1, 2$$

# System optimum (cont.)

*Types of optimal route allocations*

1. Integrated
2. Partially separated
3. Segregated (fully separated)

Necessary condition for integrated SO:

$$c_{L\bullet}^{L} c_{H\bullet}^{H} > c_{H\bullet}^{L} c_{L\bullet}^{H} + \frac{1}{4}\left(c_{H\bullet}^{L} - c_{L\bullet}^{H}\right)^2$$

Condition for UE:

$$c_{L\bullet}^{L} c_{H\bullet}^{H} > c_{H\bullet}^{L} c_{L\bullet}^{H}$$

# Analytical results

## 1: Unregulated equilibrium is "biased" towards integration

Even if the unregulated equilibrium is integrated, the system optimum may be partially separated or segregated.

**Examples**

1. *Heavies* impose disproportionately high crash risks on *Lights* $\Rightarrow$ desirable to keep *Heavies* away from *Lights*.
2. *Heavies* have disproportionately high values of travel time $\Rightarrow$ desirable to give *Heavies* lots of road space.

# Analytical results (cont.)

## 2: The System Optimum can coincide with User Equilibrium

**Example**

If the own-cost, cross-cost and environmental externalities all balance across routes.

# Analytical results (cont.)

**3: Differentiated tolls suffice to support the System Optimum**

The system optimum can be decentralized using tolls that are differentiated by vehicle type and route.

# Analytical results (cont.)

## 4: Route access restrictions may be ineffective

**Assume**

Unregulated equilibrium is integrated.

System optimum is partially separated or segregated.

**Then** [under plausible assumptions]

Restricting one vehicle type to one route raises total system costs if the other vehicle type uses both routes.

# Numerical examples

Cost coefficients include congestion and accident externalities:

$$c_{hr}^{g} = cong_{hr}^{g} + acc_{hr}^{g}, \quad g = L, H; \; h = L, H; \; r = 1, 2$$

# Numerical examples (cont.)

## (a) Congestion coefficients

Values of time: $v^L$, $v^H$

Generic passenger car equivalent: $PCE_{cong}$

Impedance factor: $\lambda$

# Numerical examples (cont.)

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Values of time: $v^L$, $v^H$

Generic passenger car equivalent: $PCE_{cong}$

Impedance factor: $\lambda$

| | | Cost incurred by | |
|---|---|---|---|
| | | *Light* | *Heavy* |
| Cost imposed by | *Light* | 1 | |
| | *Heavy* | | |

# Numerical examples (cont.)

## (a) Congestion coefficients

Values of time: $v^L,\ v^H$

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|---|---|---|---|
| | | *Light* | *Heavy* |
| Cost imposed by | *Light* | 1 | $v^H / v^L$ |
| | *Heavy* | | |

# Numerical examples (cont.)

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| | *Heavy* | | $\left(v^H / v^L\right) PCE_{cong}$ |

# Numerical examples (cont.)

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| | *Heavy* | $\lambda \cdot PCE_{cong}$ | $\left(v^H / v^L\right) PCE_{cong}$ |

# Numerical examples (cont.)

**(b) Accident coefficients**

Accident cost for a *Heavy* relative to *Light*: $\mu^H$

Generic passenger car equivalent: $PCE_{acc}$

Hazard factor: $\phi$

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Hazard factor: $\phi$

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|---|---|---|---|
| | | *Light* | *Heavy* |
| Cost imposed by | *Light* | 1 | $\mu^{H}$ |
| | *Heavy* | $\phi \cdot PCE_{acc}$ | $\mu^{H} PCE_{acc}$ |

# Base-case parameter values

Studies of PCE, lane restrictions, differential speed limits. Empirical evidence is mixed:

PCE of trucks varies with

- Mix of cars and trucks
- Terrain
- Weather

Crash rates for trucks

- Lower: overall, rear-end
- Higher: fatal, sideswipe

Car drivers

- Dislike presence of trucks
- Increase headways which reduces capacity

# Base-case parameter values

| | Route 1 | Route 2 |
|---|---|---|
| Capacities | 4,000 PCE /hour | 2,000 PCE /hour |
| Speed limits | 65 mph (105 kph) | 65 mph (105 kph) |
| Lengths | 32.5 miles (52 km) | 32.5 miles (52 km) |
| Total trips by *Lights* and *Heavies* | 40,000 | |
| Proportion of *Heavies* | 20% | |
| | | |
| Travel costs | ***Light* vehicles** | ***Heavy* vehicles** |
| Fixed costs | \$0.194/mile (€0.08/km) | \$0.42/mile (€0.17/km) |
| Values of time | \$12/hour (€8/hr) | \$50/hour (€33/hr) |
| Congestion PCE for *Heavies* ( $PCE_{cong}$ ) | | 2 |
| Relative impedance of *Lights* by *Heavies* ( $\lambda$ ) | 1 | |
| Accident PCE for *Heavies* ( $PCE_{acc}$ ) | | 0.75 |
| Relative crash hazard for *Lights* ( $\phi$ ) | 1 | |
| Relative cost of accident for *Heavies* ( $\mu^H$ ) | | 1 |
| Environmental costs | \$0.0223/mile (\$0.009/km) | \$0.2153/mile (\$0.09/km) |

# Base-case-parameter solution

## Unregulated equilibrium is integrated

Compared to *Lights*, *Heavies* cause more congestion than accidents but are more averse to congestion than accidents.

$\Rightarrow$ *Heavies* prefer to travel with *Lights*

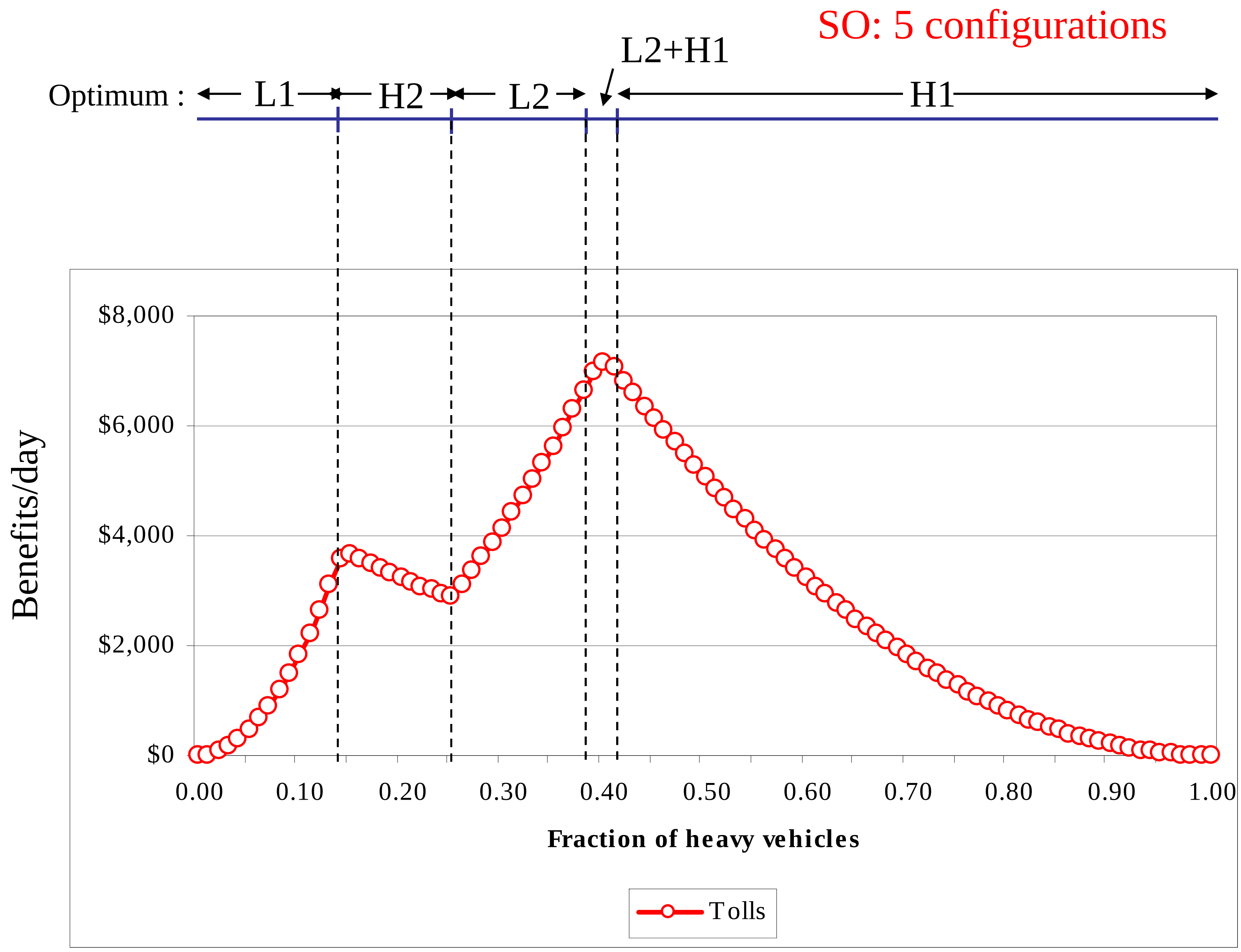
$\Rightarrow$ *Lights* prefer to travel with *Heavies*

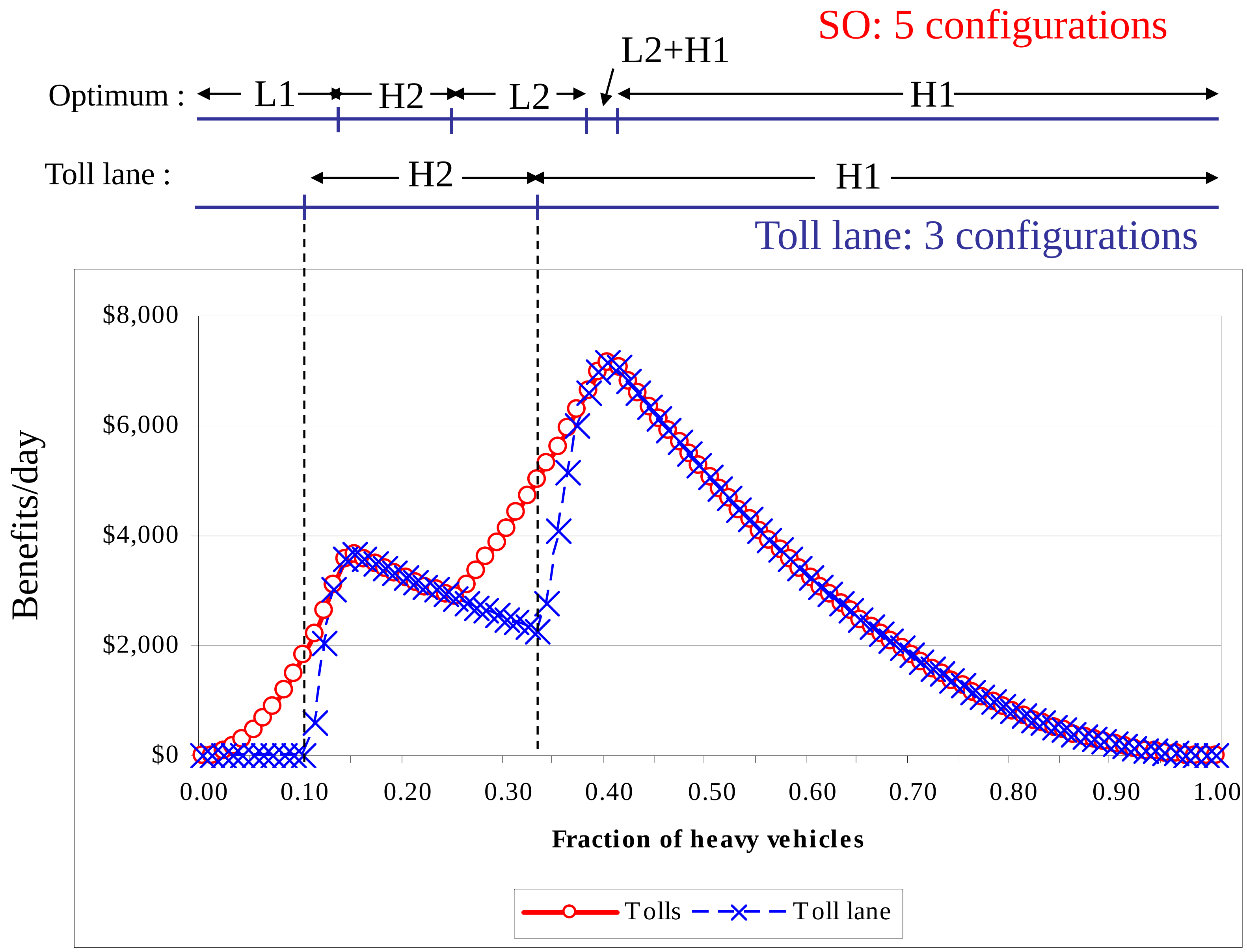
## System optimum same as Unregulated equilibrium

Conditions of Result 2 satisfied

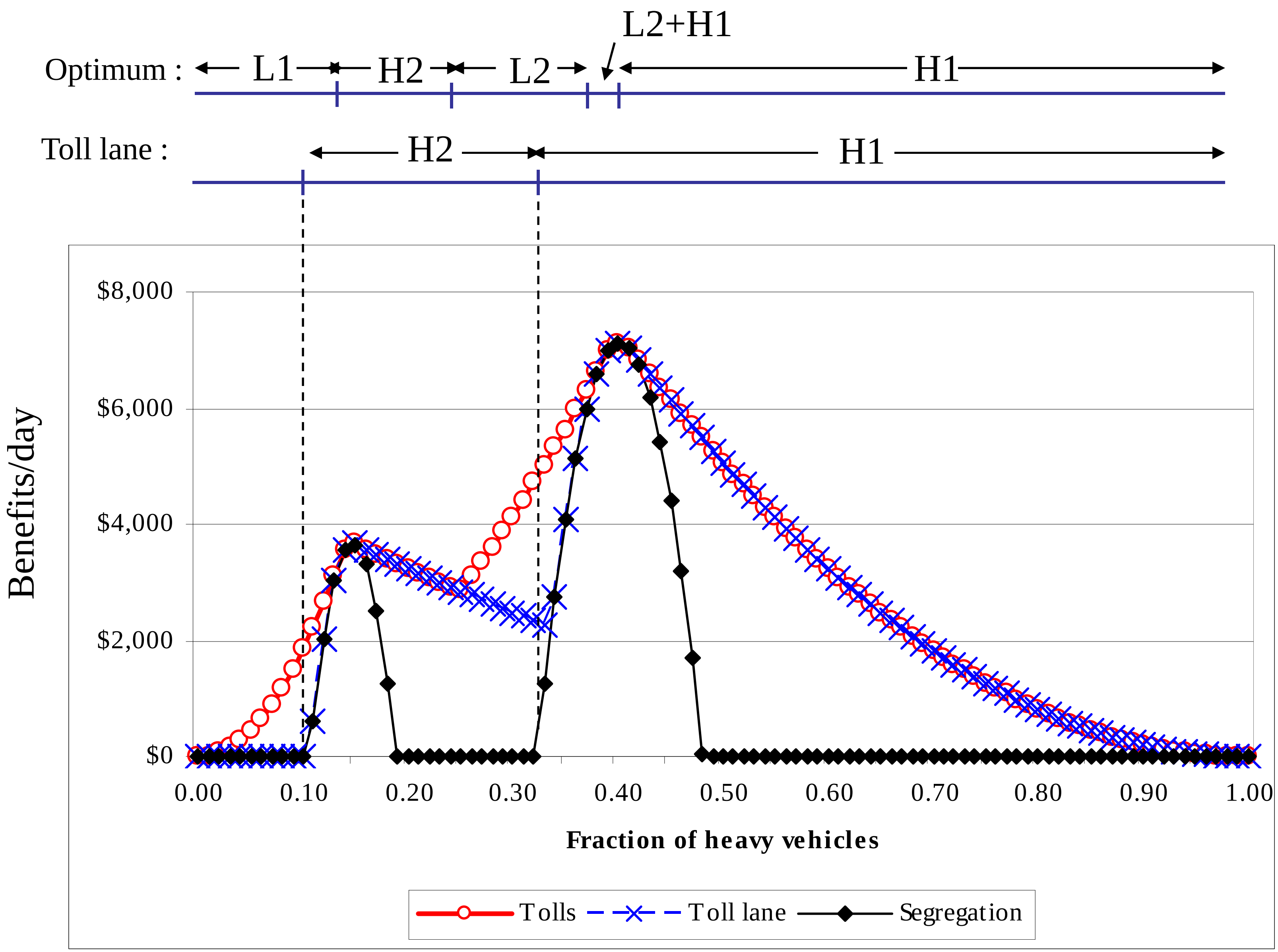
# Variant 1: $v^H = \$75/h$

Base case: $v^H = \$50/h$


SO: 5 configurations
L2+H1
Optimum :
L1
H2
L2
H1
$8,000
$6,000
$4,000
$2,000
$0
Benefits/day
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Fraction of heavy vehicles
Tolls




Route/lane access restrictions useless



L2+H1
Optimum :
L1
H2
L2
H1
Toll lane :
H2
H1
Benefits/day
$8,000
$6,000
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Fraction of heavy vehicles
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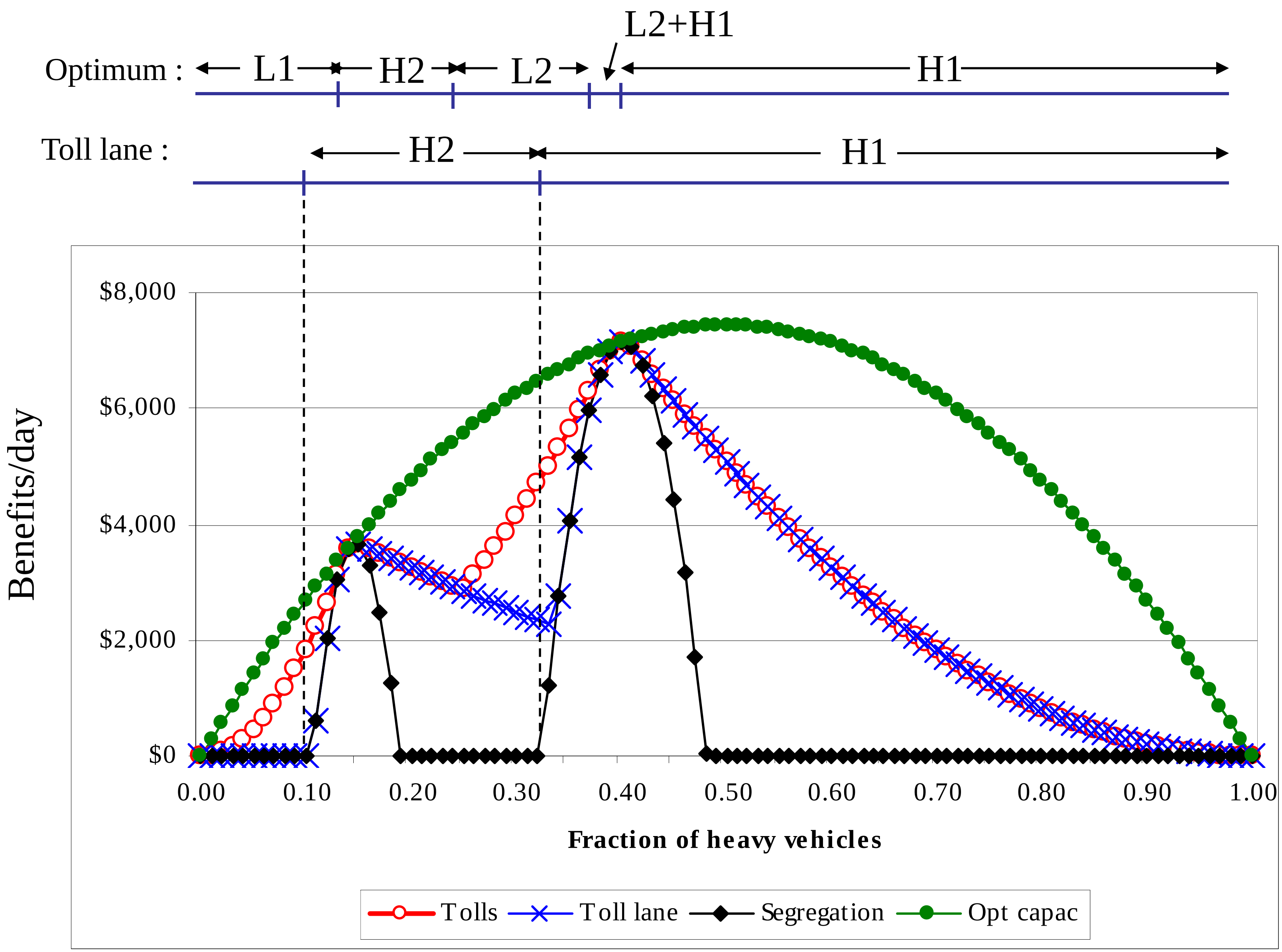
Toll lane
Segregation



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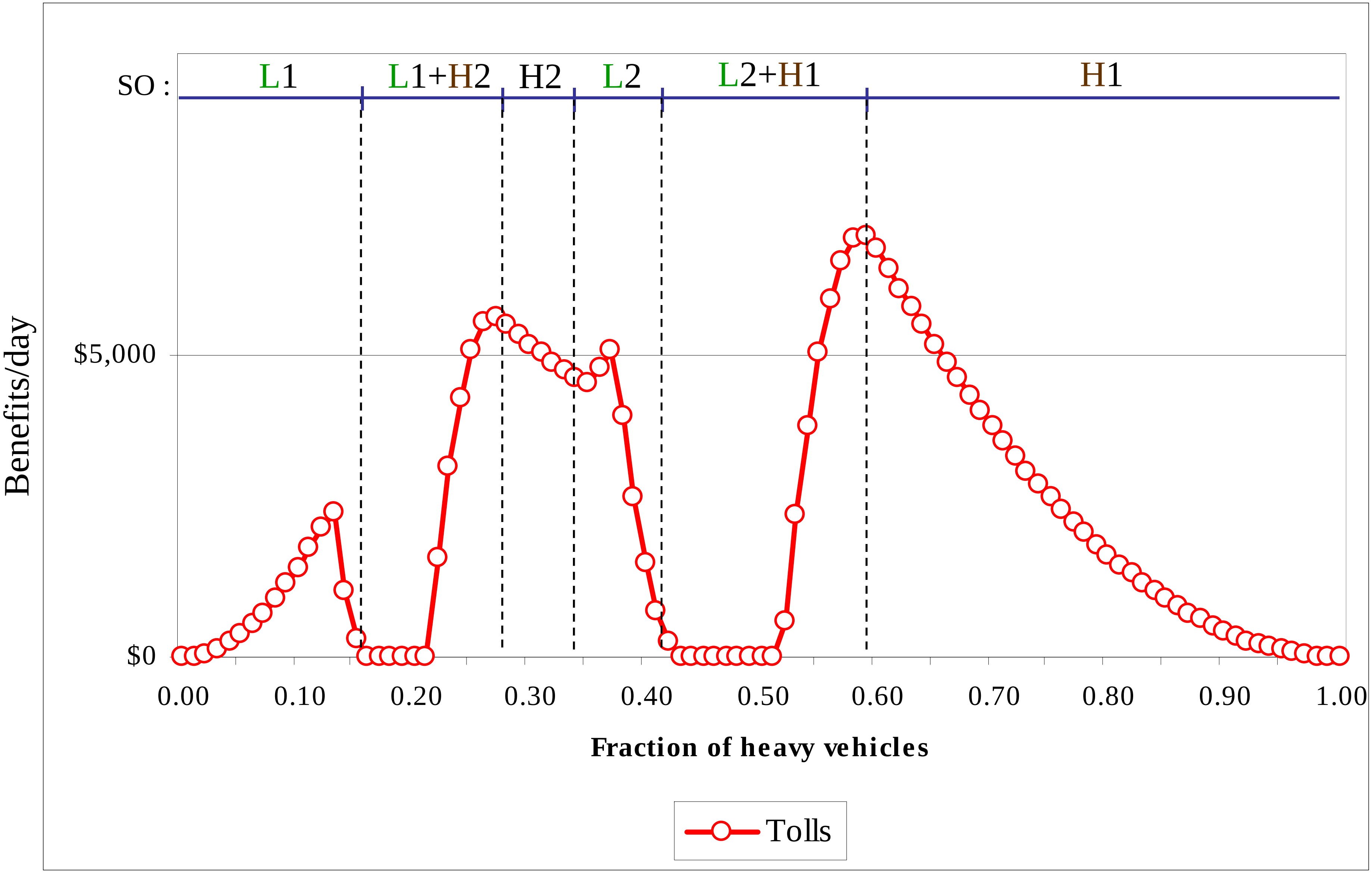
Tolls
Toll lane
Segregation
Opt capac

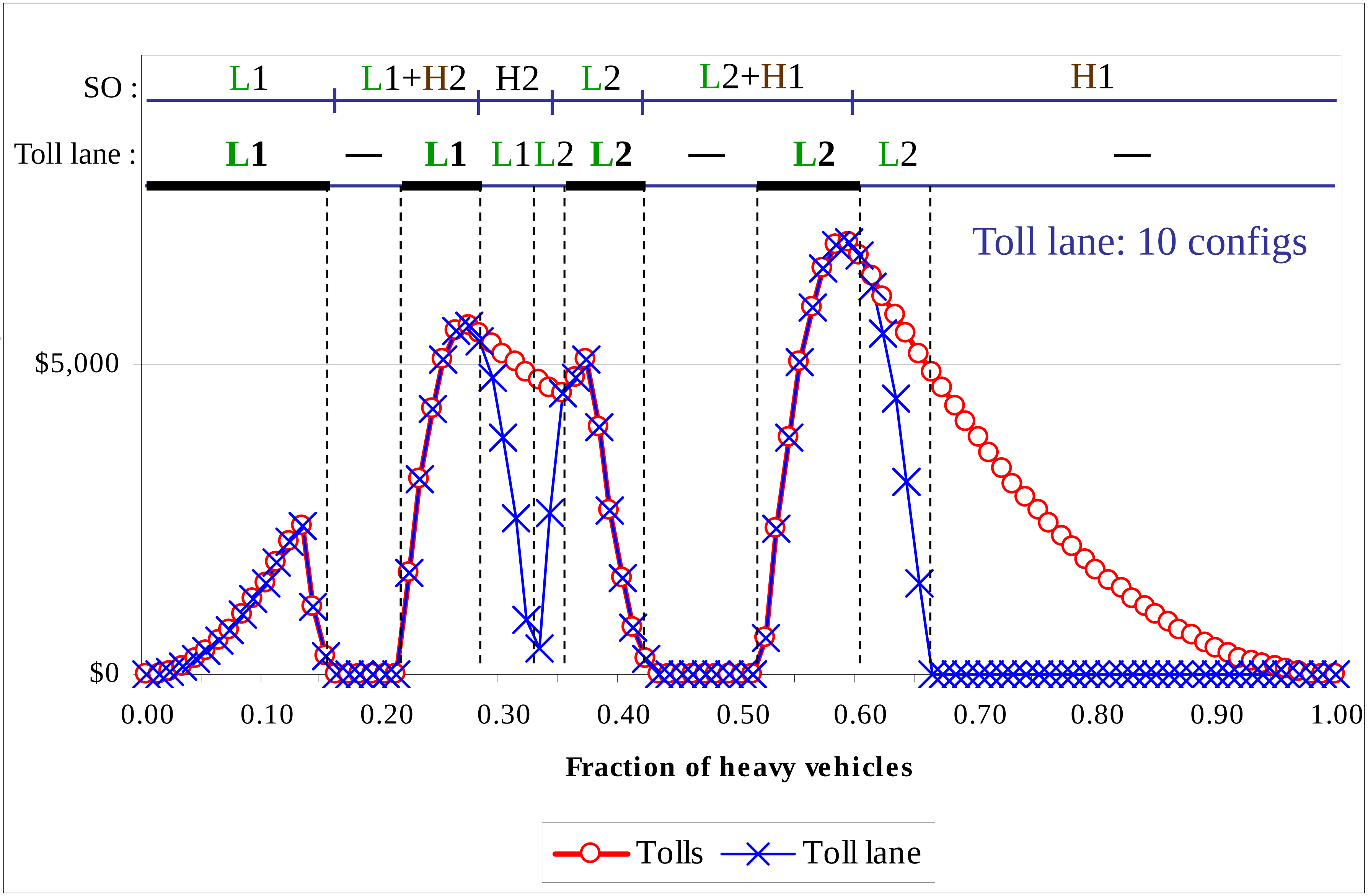
# Variant 2: $v^H = \$25/h,\ \lambda = 2$

Base case: $v^H = \$50/h,\ \lambda = 1$

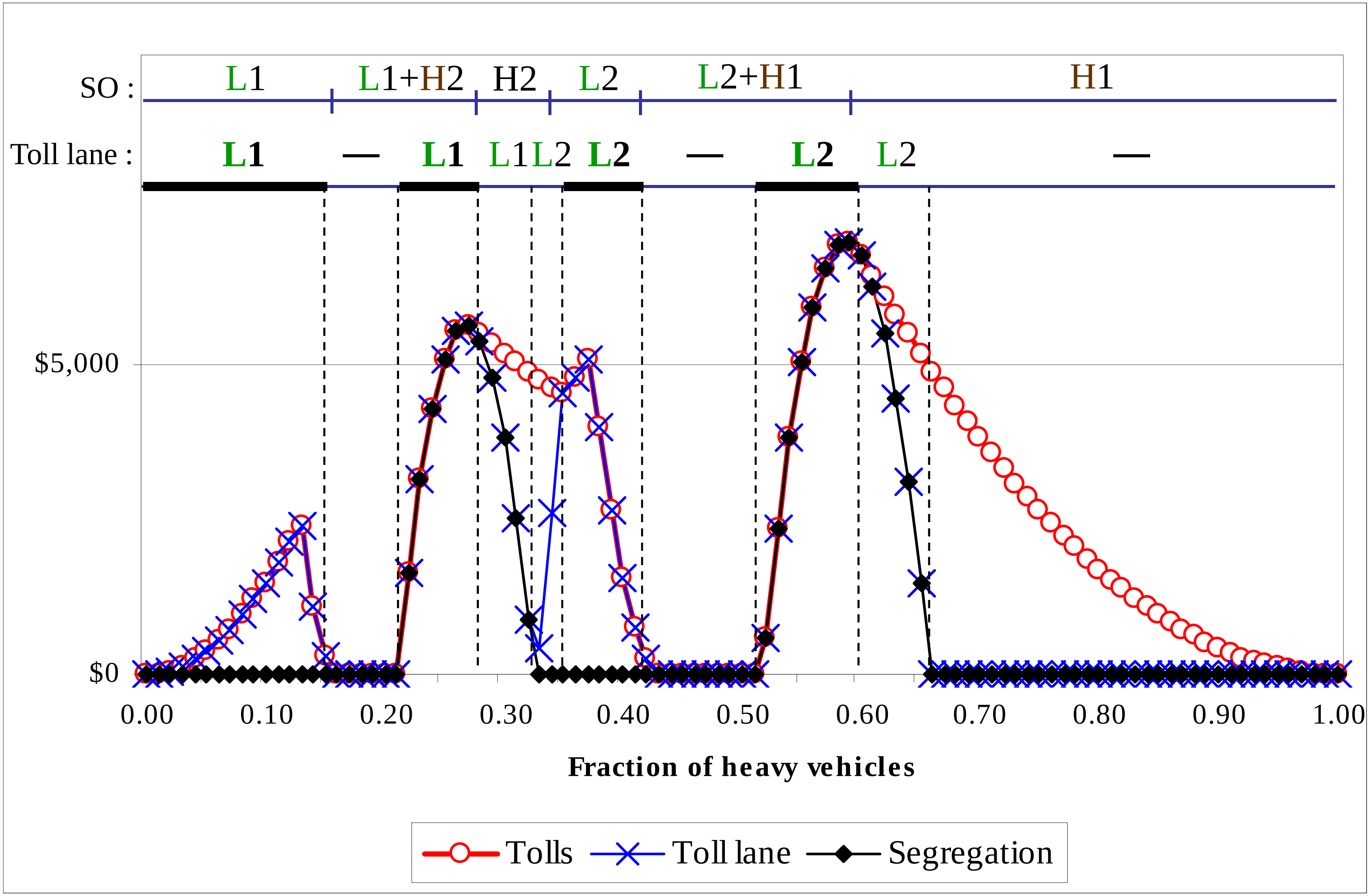
## SO: 6 configurations



SO: 6 configurations

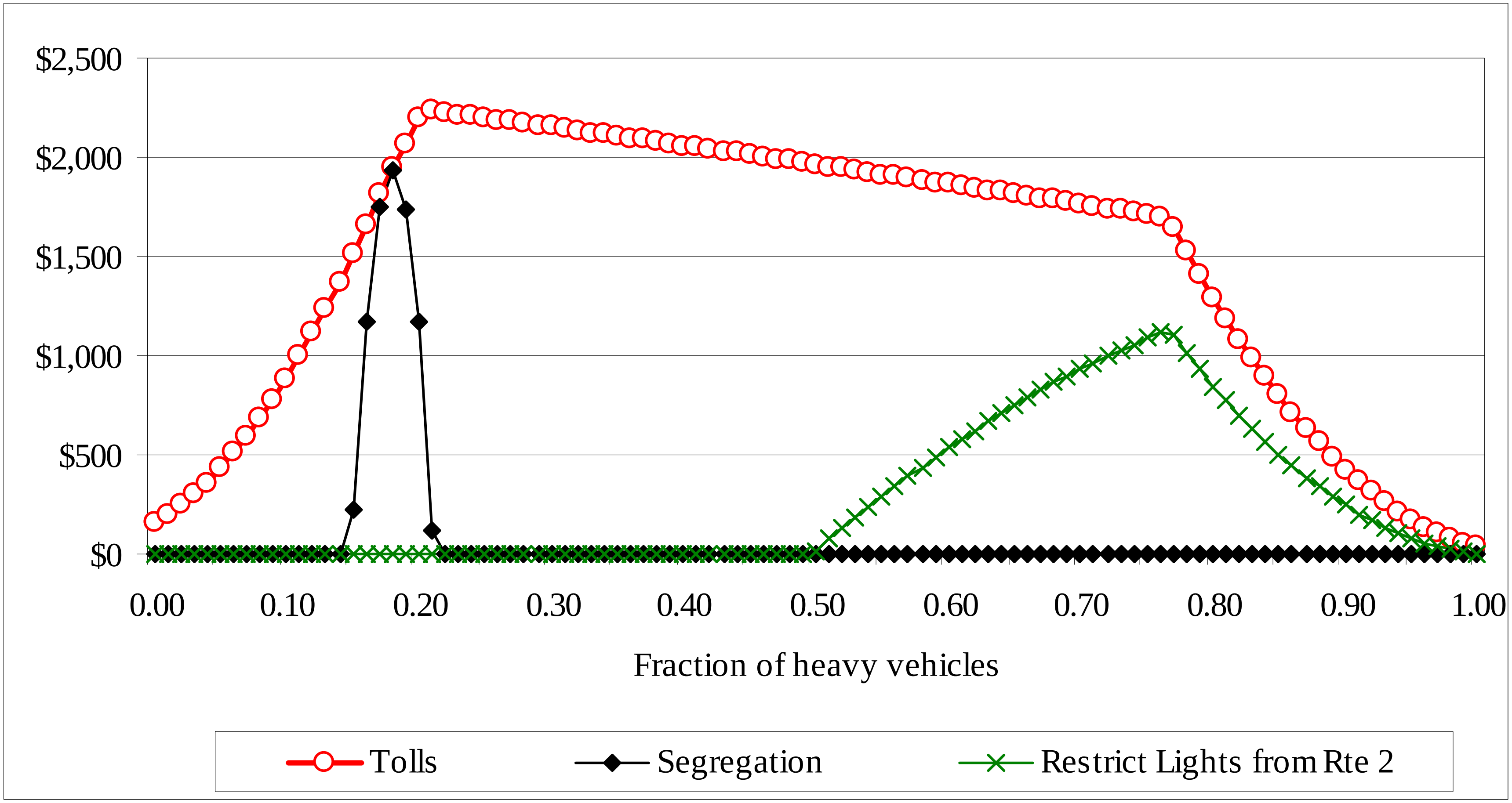



Route/lane access restrictions useless

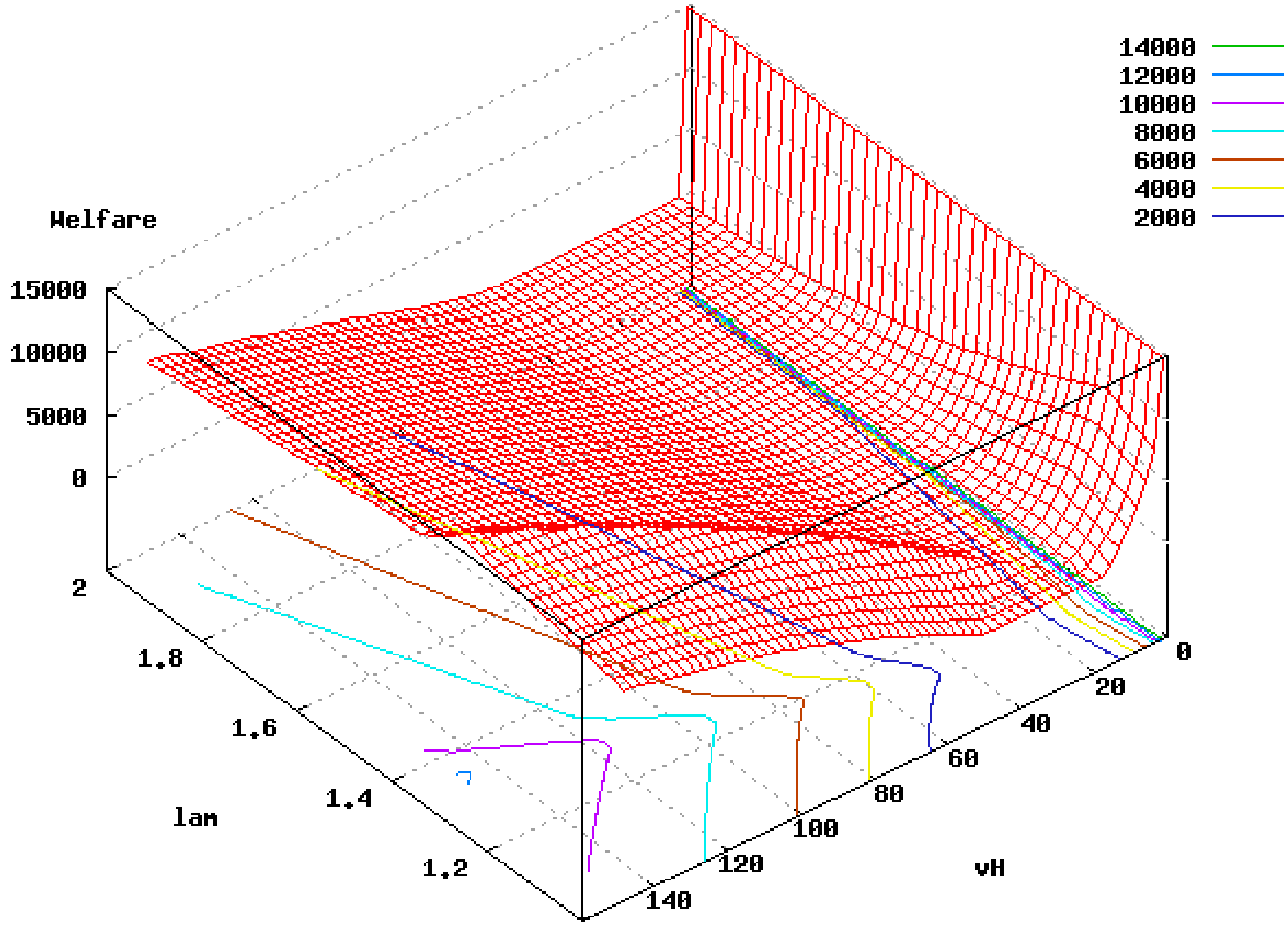



Segregation: 5 configurations

# Variant 3: Route 2 is 2.5 miles shorter



# Variant 4: Two-way variation



# Conclusions from model

1) Benefits from intervention sensitive to various parameters:

Proportions of *Lights* and *Heavies*

Lane capacity indivisibilities

PCEs for congestion and PCEs for accidents

Values of travel time (relative and absolute)

2) Nonmonotonic variation of benefits with parameters; e.g. fraction of *Heavies*, VOT for *Heavies*

3) No presumption that separation is desirable

# Model extensions

## *Elastic demand*

- Alternative toll-free corridors (traffic diversion problems)

## *Trip-timing preferences*

- Truck and auto flows peak at different times.
- Constraints on trucks: Hours of service regulations, maritime terminal operating hours, neighborhood curfews, shippers' hours, delivery tours.

## Heterogeneity within types

VOT, PCE, road damage

Desired vehicle speeds $\Rightarrow$ scale economies with respect to number of lanes



Need simulation models