UCLA IPAM Equity in Transportation Workshop, January 22-26, 2024

Achieving more equitable market-based congestion-mitigating policies

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Outline

1 Equity concern of congestion pricing

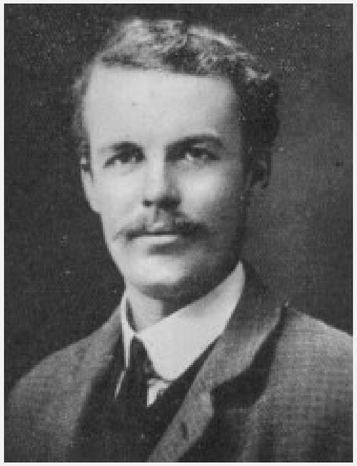
2 Pricing design with explicit equity consideration

3 Tradable mobiltiy credits to address equity concerns

4 Concluding remarks

Congestion Pricing

- Charge travelers the marginal external costs of their trips (Pigou, 1920)
- Use tolls to incentivize travelers to change their travel choices to reduce traffic congestion, enhance system performance and improve social welfare
- A market-based policy, as compared to command-and-control policies such as driving restrictions or bans



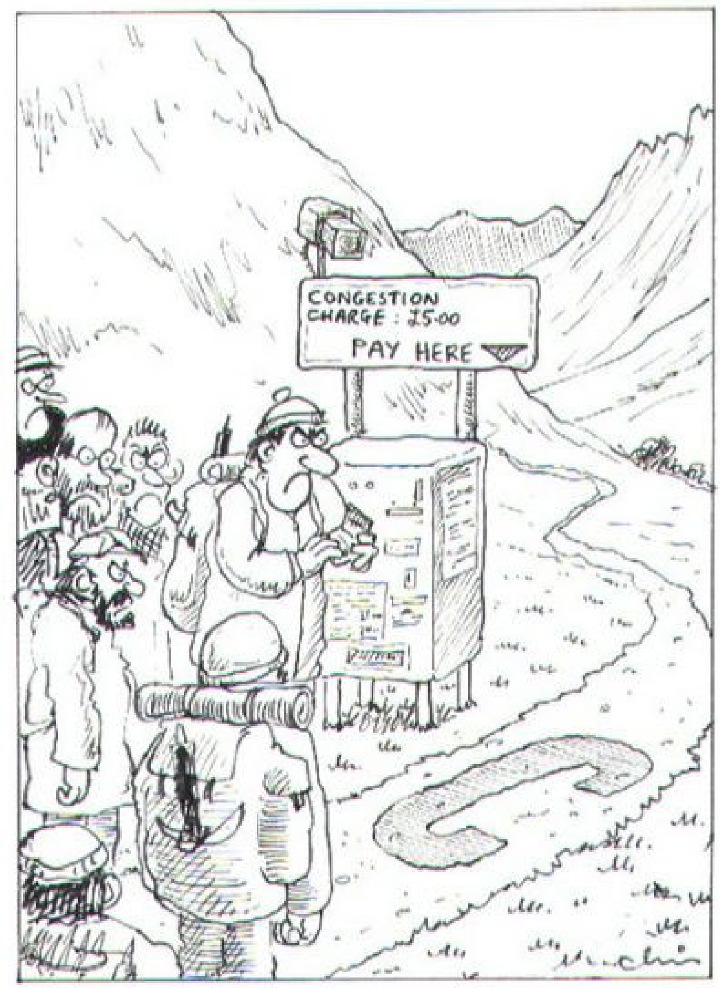
Arthur Cecil Pigou

Congestion Pricing (Cont'd)

- Many transportation economists and planners concur that implementing pricing on limited road capacity can mitigate traffic congestion and optimize urban land use (Lindsey, 2006; Elisasson, 2016).
- Evidence from various cities (e.g., Singapore, London, Stockholm and Milan) confirms that when effectively designed, congestion pricing not only functions as intended but also yields social benefits that significantly outweigh the initial and operational expenditures (Danielis et al., 2012; Eliasson, 2009; Olszewski and Xie, 2005; Santos et al., 2008).
- However, congestion pricing remains a very tough sell to the public

Equity Concerns

- Much of the public opposition centers on the perceived inequity
  - Congestion pricing harms the poor who may have to pay more due to their inflexible schedules, or be forced to switch to less desirable routes, departure times or travel modes
- In practice, otherwise justified plans are often thwarted by the concerns and debates over their equity impacts



2007 UK Proposal for National Road Pricing

Number10.gov.uk BETA
The official site of the Prime Minister's Office.

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This petition is now closed, as its deadline has passed.

We the undersigned petition the Prime Minister to Scrap the planned vehicle tracking and road pricing policy. More details

Submitted by Peter Roberts – **Deadline to sign up by:** 20 February 2007 – **Signatures:** 1,811,424

Petition update, 21 February 2007

The Prime Minister has responded to the petition. You can read his response and other views here:
http://www.pm.gov.uk/output/Page11050.asp

Current signatories

Because there are so many signatories, only the most recent 500 are shown on this page.

- Judith laslett
- keith jennings
- Julia Hodgins
- Alex Cargill
- Neil Gilbride
- Bohdan Solyanyk
- Aaron Emms
- Charles Beardow

More details from petition creator

The idea of tracking every vehicle at all times is sinister and wrong. Road pricing is already here with the high level of taxation on fuel. The more you travel - the more tax you pay.

It will be an unfair tax on those who live apart from families and poorer people who will not be able to afford the high monthly costs.

Please Mr Blair - forget about road pricing and concentrate on improving our roads to reduce congestion.

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Addressing Equity Concerns

- The concerns can be largely addressed by a well-designed pricing scheme that charges the right amount of tolls at right locations and redistribute toll revenues wisely (FHWA, 2008)
- A modeling framework is needed to support the decision-making. It should capture the distributional effects of pricing schemes on different individuals and groups, thereby facilitating meaningful discussion on equity
- Income-based equity
  - The distribution of impacts between individuals and groups that differ in income
  - A pricing scheme is deemed to be more equitable if it leads to a more uniform distribution of wealth across population

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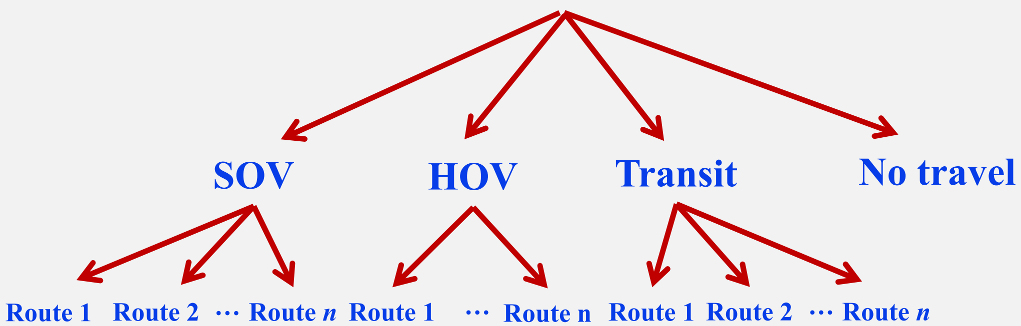
Basic Considerations

- A general multimodal transportation network
  - Three types of facilities, i.e., transit lines, high-occupancy/toll (HOT) and regular lanes
- Multiple user groups with different incomes and different preferences among four modes:
  - No travel, transit, drive alone (SOV), and car pool (HOV)
  - The number of travelers between each OD pair is fixed
- Now assuming a pricing scheme is given, let's model the resulting tolled network equilibrium and capture its distributional effects

Choices of Mode and Route

- Nested Logit Model



$$P_k^{w,m,g} = \frac{\exp\left(\frac{v_k^{w,m,g}}{\theta^{w,m,g}}\right)}{\sum_{j\in K^{w,m}} \exp\left(\frac{v_j^{w,m,g}}{\theta^{w,m,g}}\right)} \cdot \frac{\exp\left(\bar{v}^{w,m,g}\right)}{\sum_{m'\in M} \exp\left(\bar{v}^{w,m,g}\right)}$$

$$\bar{v}^{w,m,g} = ln\left(\sum_{j\in K^{w,m}} \exp\left(\frac{v_j^{w,m,g}}{\theta^{w,m,g}}\right)\right)^{\theta^{w,m,g}}$$

Utility Function

- Linear-in-income

$$v = \beta_0 + \beta_1 T + \beta_2 (y_0 - \tau)$$

Travel Time | Income | Toll

- The above conventional specification with constant marginal utility of income may lead to an underestimate of the regressiveness of a pricing scheme (e.g., Franklin, 2006; Bureau and Glachant, 2008)

Nonlinear Utility Function

- Generalized Leonief

$$\boldsymbol{v} = \beta_0 + \beta_1 T + \beta_2 \sqrt{T} + \beta_3 (y_0 - \tau) \\ + \beta_4 \sqrt{y_0 - \tau} + \beta_5 \sqrt{T} \sqrt{y_0 - \tau}$$

- Translog

$$\boldsymbol{v} = \beta_0 + \beta_1 \ln T + \beta_2 \ln^2 T + \beta_3 \ln(y_0 - \tau) + \beta_4 \ln^2(y_0 - \tau) + \beta_5 \ln T \ln(y_0 - \tau)$$

Tolled User Equilibrium

- The behavioral considerations lead to a multimodal network user equilibrium where the perceived utility of each traveler is maximized.
- The corresponding flow distribution under a pricing scheme can be obtained by solving the variational inequality (VI) as follows:

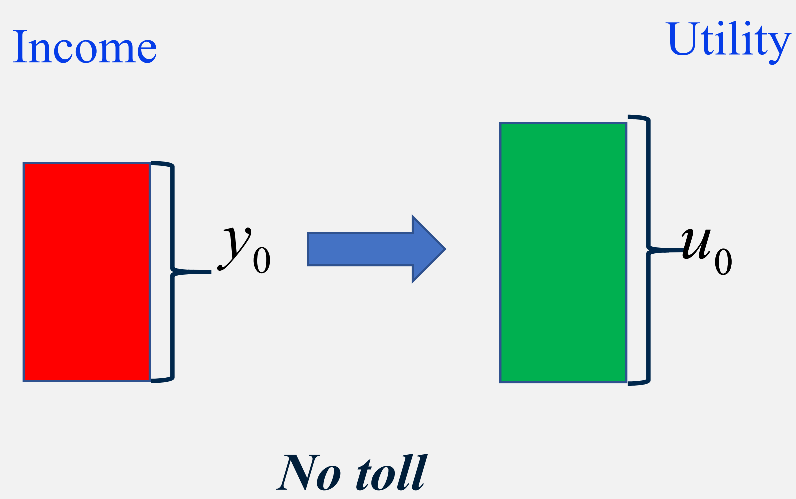
$(f^*, d^*) \in \Phi$ is in user equilibrium if

$$\sum_{g\in G}\sum_{w\in W}\sum_{m\in M}\sum_{k\in K^{w,m}}\left(-v_k^{w,m,g}(f^*) + \theta^{w,m,g}\ln f_k^{w,m,g^*}\right)\cdot\left(f_k^{w,m,g} - f_k^{w,m,g^*}\right)$$
$$+\sum_{g\in G}\sum_{w\in W}\sum_{m\in M}(1-\theta^{w,m,g})\ln d^{w,m,g^*}\cdot\left(d^{w,m,g} - d^{w,m,g^*}\right) \geq 0,$$
$$\forall (f,d)\in\Phi$$

Individual Welfare Measure

- Equivalent Income
  - A measure of how wealthy a traveler feels under the pricing scheme
  - The income level that allows the individual to experience under the no-pricing scenario the same level of utility as the original income does under the pricing scheme

$$e^{w,g}(\tau) = arg\{z: u^{w,g}(z, 0) = u^{w,g}(y^g, \tau)\}$$



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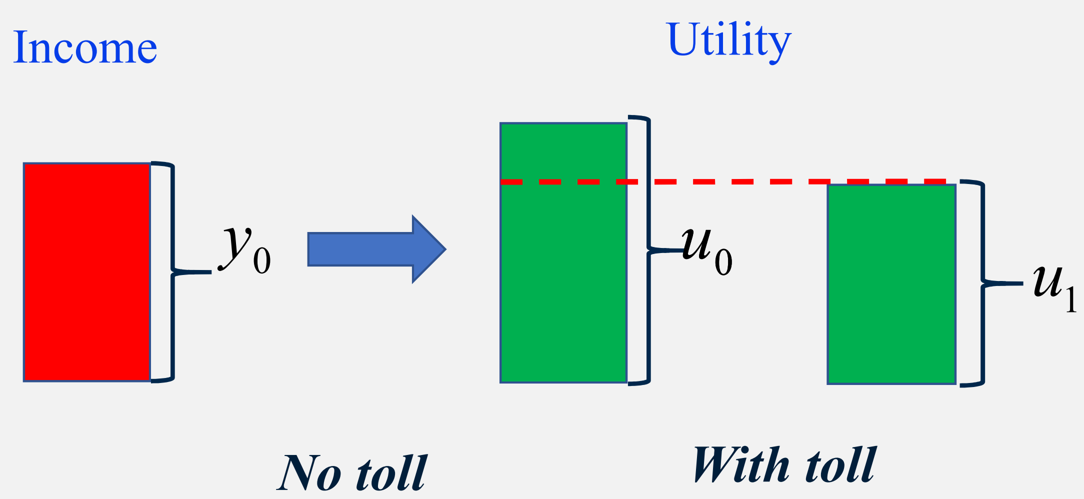

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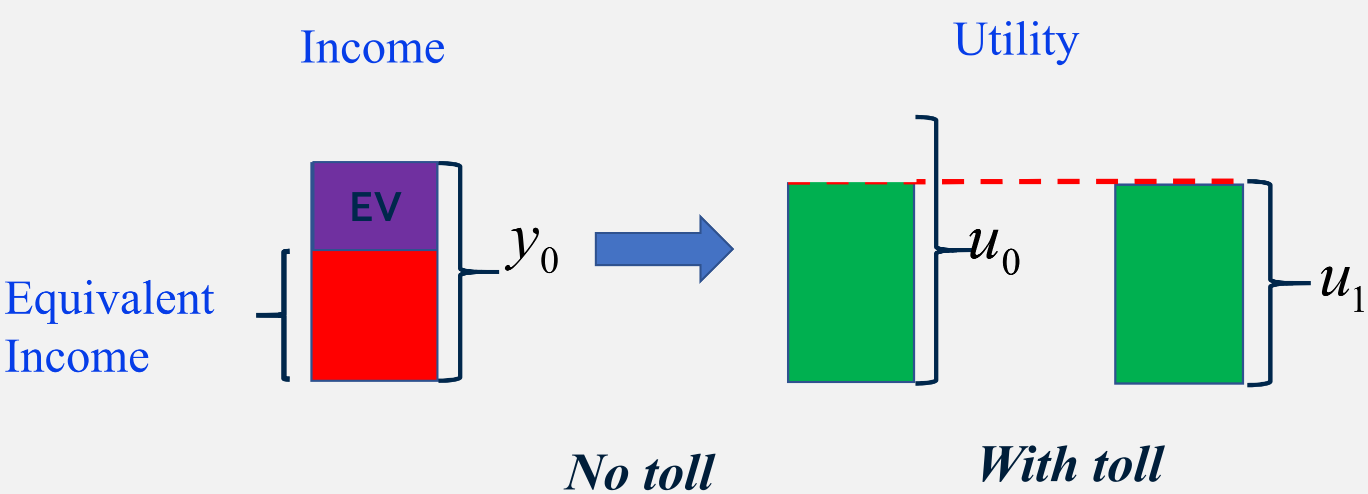

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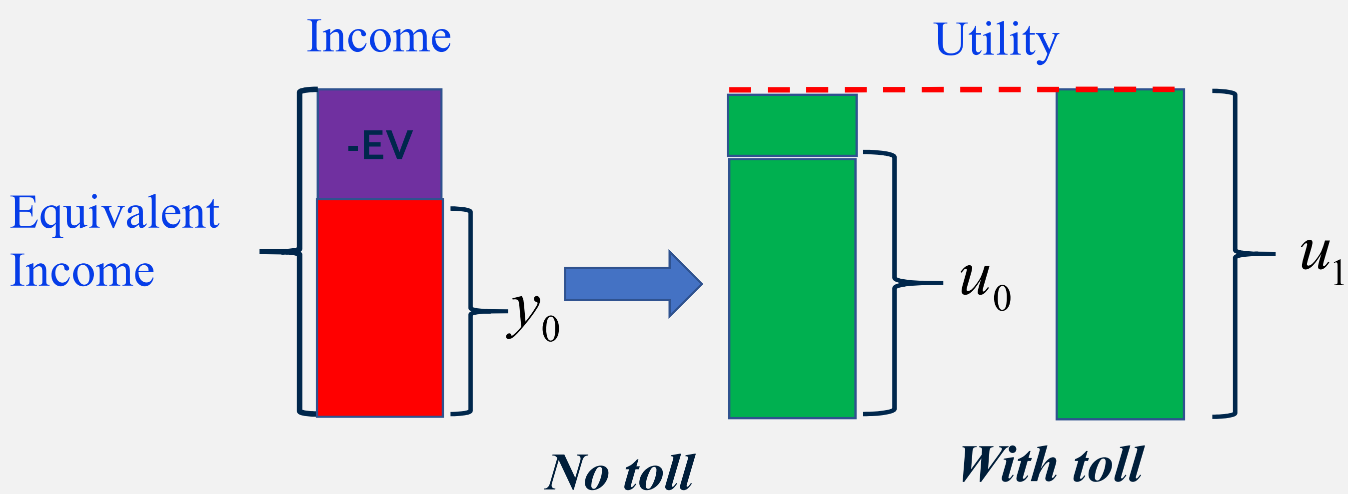


Individual Welfare Measure (Cont'd)

- Due to the existence of the random error term in the utility function, the equivalent income is also random for each individual traveler

$$e^{w,g}(\tau) = arg\{z: u^{w,g}(z,0) = u^{w,g}(y^g,\tau)\}$$

- Expected equivalent income (Dagsvik and Karlstrom, 2005)

$$E\left(e^{w,g}(\tau)\right)$$
$$= \sum_{m^0 \in M} \sum_{k^0 \in K^{w,m^0}} \int_0^{p_{k^0}^{w,m^0,g}(\tau)} \frac{\left(\sum_{k \in K^{w,m^0}} \exp\left(\frac{h_k^{w,m^0,g}(z,\tau)}{\theta^{m^0}}\right)\right)^{\theta^{m^0}-1} \cdot \exp\left(\frac{v_{k^0}^{w,m^0,g}(y^g,0)}{\theta^{m^0}}\right)}{\sum_{m \in M}\left(\sum_{k \in K^{w,m}} \exp\left(\frac{h_k^{w,m,g}(z,\tau)}{\theta^m}\right)\right)^{\theta^m}} dz$$

$$v_{k^0}^{w,m^0,g}(y^g,\tau) = v_{k^0}^{w,m^0,g}(p_{k^0}^{w,m^0,g}(\tau),0)$$

$$h_k^{w,m^0,g}(z,\tau) = max\ (v_k^{w,m^0,g}(y^g,\tau), v_k^{w,m^0,g}(z,0))$$

System Performance Measures

- Social welfare
  - The sum of the total expected equivalent income (user benefit) and the toll revenue (producer benefit)
- Equity
  - Gini coefficient: calculated based on expected equivalent income with 0 being complete equality and 1 being complete inequality

$$GN(\tau) = \frac{1}{2 \cdot \left(\sum_{g \in G} \sum_{w \in W} D^{w,g}\right)^2 \cdot \overline{E\left(e(\tau)\right)}} \cdot \sum_{g_1, g_2 \in G} \sum_{w_1, w_2 \in W} \left(D^{w_1,g_1} \cdot D^{w_2,g_2} \cdot \left|E\left(e^{w,g}(\tau)\right) - E\left(e^{w,g}(\tau)\right)\right|\right)$$

  - A more equitable pricing scheme will lead to a smaller value of the Gini coefficient

Design of Pricing Scheme

$$\max_{\tau,d,f} \alpha \cdot \frac{SB(\tau)}{SB(0)} - (1-\alpha) \cdot \frac{GN(\tau)}{GN(0)}$$

$s.t.$

$$\sum_{g\in G}\sum_{w\in W}\sum_{m\in M}\sum_{k\in K^{w,m}} \left(-v_k^{w,m,g}(f^*) + \theta^{w,m,g}\ln f_k^{w,m,g^*}\right)\cdot\left(f_k^{w,m,g} - f_k^{w,m,g^*}\right)$$

$$+\sum_{g\in G}\sum_{w\in W}\sum_{m\in M}(1-\theta^{w,m,g})\ln d^{w,m,g^*}\cdot\left(d^{w,m,g} - d^{w,m,g^*}\right) \geq 0 \ \ \forall (f,d)\in\Phi$$

$$(f^*, d^*) \in \Phi$$

$$\tau_l^m \geq 0, \qquad \forall l \in L, m \in \{S, H\}$$

$$\tau_l^S = \tau_l^H, \qquad \forall l \in L_{RT}$$

$$\tau_l^R = 0, \qquad \forall l \in L$$

$$\sum_{g\in G}\sum_{w\in W}\sum_{m\in M}\sum_{k\in K^{w,g}} f_k^{w,m,g}\sum_{l\in L}\Delta_{k,l}\tau_l^m \geq 0$$

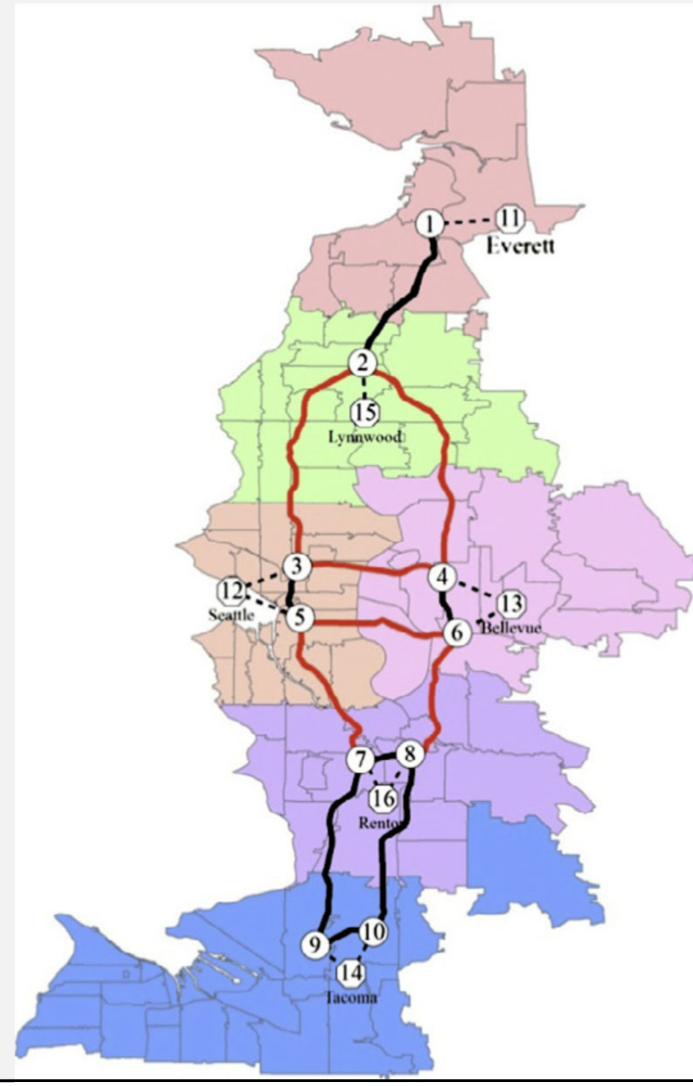
Solution Algorithm

- Mathematical program with equilibrium constraints (MPEC), a class of problems difficult to solve
- Compounding the difficulty is that the computation of the expected equivalent income involves numerical integration
- Derivative-free algorithm
  - Compass search algorithm
  - SID-PSM algorithm: a pattern search method guided by simplex derivatives proposed by Custódio and Vicente (2007) and Custódio et al. (2010)

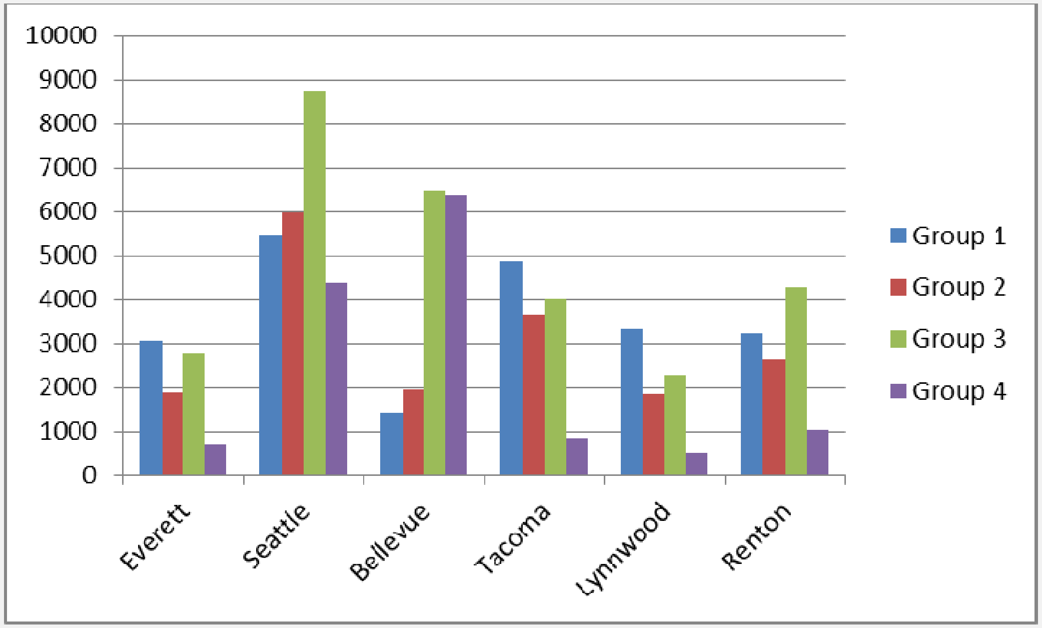
Numerical Example

- Seattle Regional Freeway Network
  - Four income groups ($20,000; $40,000; $70,000; $120,000)
  - Translog utility function (Franklin, 2006)

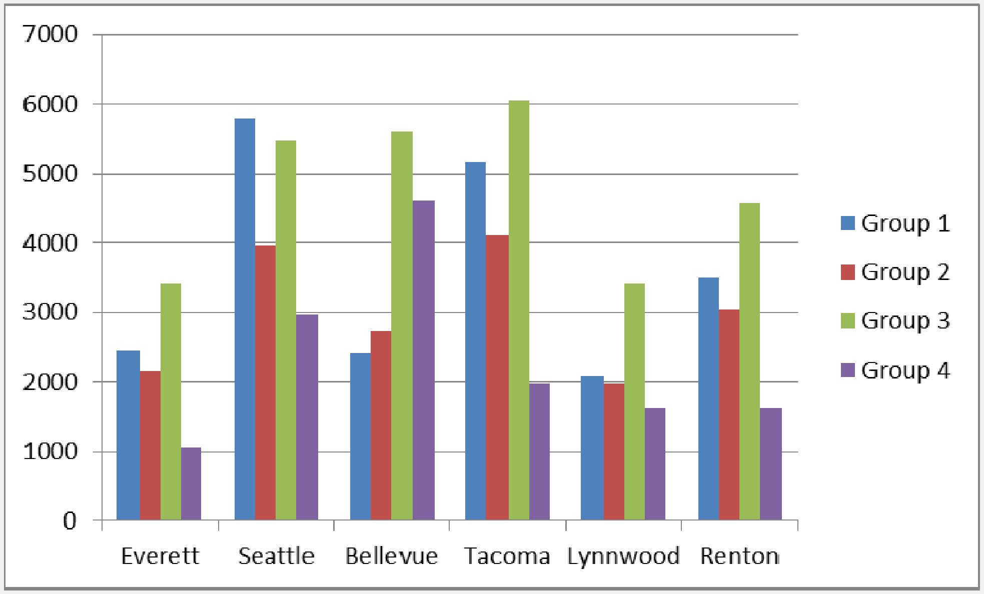
$$v_k^{w,m,g} = \beta_0^R \log \gamma y^g + \beta_1 \ln\left(y^g - C_k^{w,m}\right) + \beta_2 \ln T_k^{w,m} + \beta_3 \ln^2 T_k^{w,m}$$



Travel Demand

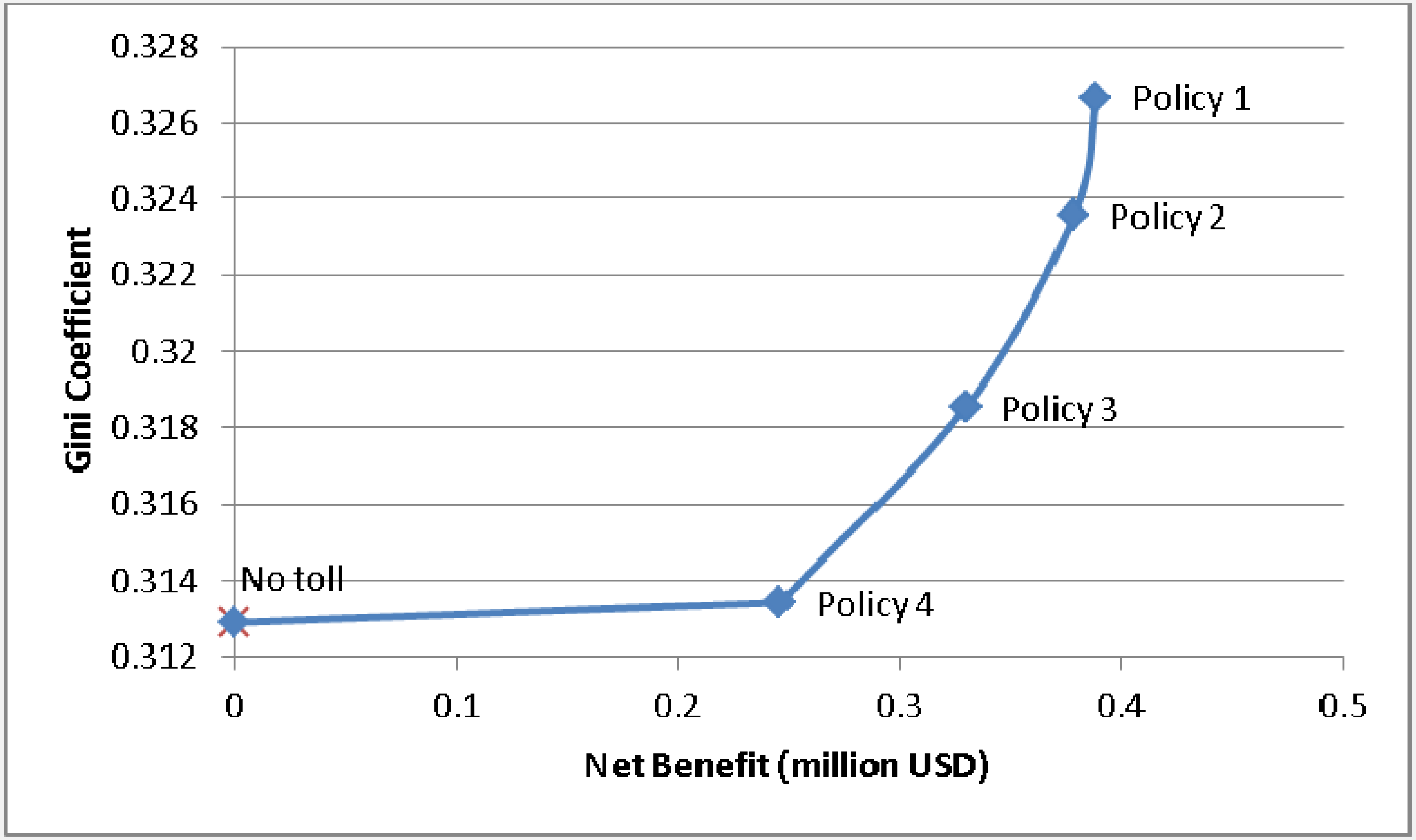


Production

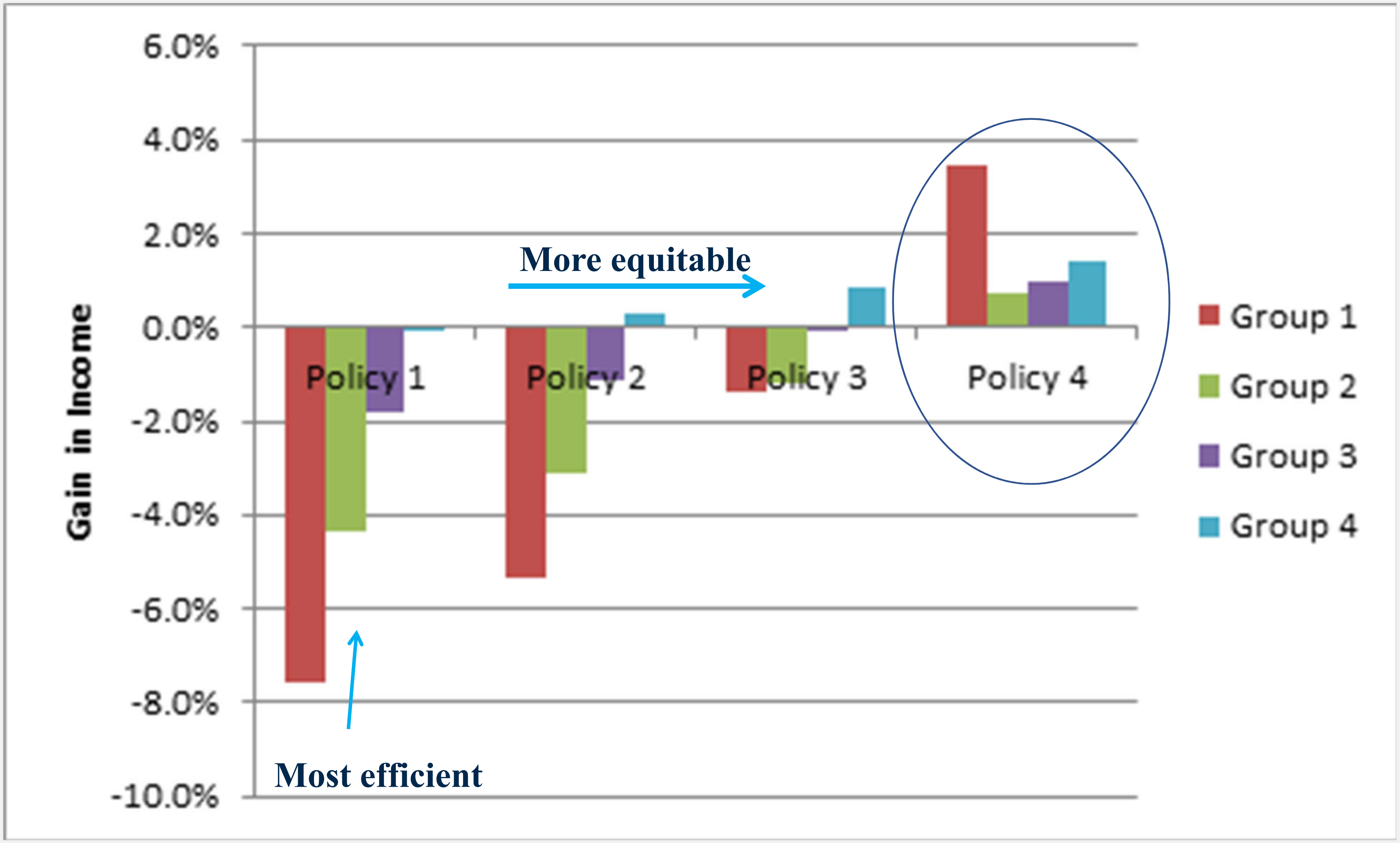


Attraction

Optimal Pricing Schemes



Benefit Distribution



Optimal Pricing Schemes

More efficient

More equitable

Link	Policy 1 Auto	Policy 1 Transit	Policy 2 Auto	Policy 2 Transit	Policy 3 Auto	Policy 3 Transit	Policy 4 Auto	Policy 4 Transit
3	5.00	1.00	0.00	-1.00	0.00	-5.00	0.00	-15.00
4	5.00	1.00	1.00	0.00	0.00	-4.25	0.00	-15.00
5	10.25	0.00	8.25	-2.00	3.75	-10.00	2.25	-16.00
6	13.00	-1.00	13.00	-1.00	11.50	-4.00	12.50	-1.00
8	10.00	0.50	8.25	-2.50	3.25	-8.00	0.00	-15.50
9	13.00	-0.25	12.75	-2.25	10.75	-3.25	11.00	-0.25
12	10.00	0.00	10.00	0.00	7.75	-3.75	6.00	0.00
13	20.00	-2.00	20.00	-6.00	16.00	-12.00	12.00	-18.00
15	11.50	0.00	11.00	-1.75	9.00	-2.75	5.50	0.00
16	15.00	-2.00	15.00	-6.00	11.75	-10.00	7.00	-18.00
17	15.00	0.25	11.25	-5.50	6.75	-11.75	2.00	-20.00
20	8.00	-0.50	4.25	-4.50	0.75	-10.25	0.00	-16.50

Observations

- When efficiency is maximized, low-income travelers suffer the most; i.e., the social-welfare maximizing scheme is regressive
- When equity is given enough weight, low-income and high-income travelers both benefit more than mid-income travelers
  - Low-income travelers: transit subsidy
  - High-income travelers: reduction in driving time
- Better equity is achieved via heavier transit subsidy
- When improving efficiency, Pareto improvement is possible, although the equity measure still becomes worse
- It appears that improving social welfare would inevitably worsen income-based equity
  - Most equitable scheme is no toll

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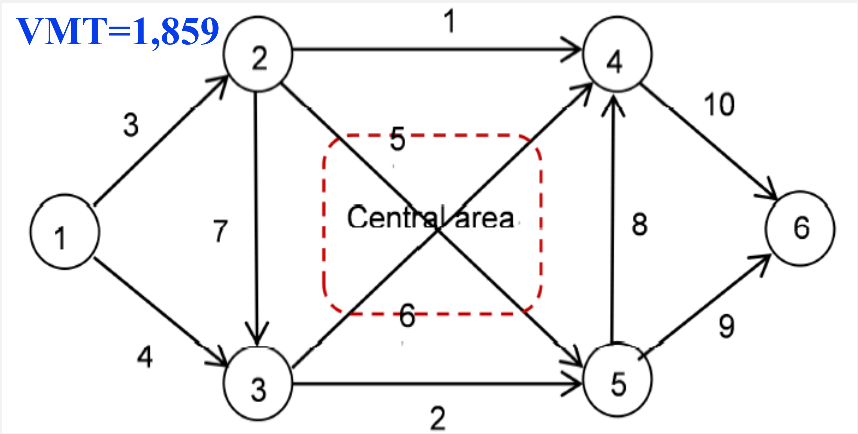
Tradable Mobility Credits

- Credits or permits are distributed by a government agency for free
- Travelers are required to pay a certain number of credits to access transportation facilities
- The credits can be traded among travelers in a market created by the government. The price is determined by the market through free trading
- By deciding the initial credit distribution and the subsequent credit charging scheme, the government agency can achieve its policy goals

Example

- Control objective
  - Reducing VMT to be less than 1,000
- Tradable credit scheme
  - Allocating 1,000 credits to the travelers
  - Charging one credit for each mile travelled
- Under idealized conditions (e.g., no transaction cost), the VMT of the network will be 1,000, and the market price of each credit is 1.503

$$D_{16}(u_{16}) = 500\exp(-0.05u_{16})$$



Analysis of Tradable Credits (Cont'd)

- Equilibrium

$$V = \left\{(\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}) : v_a = \sum_{w} \sum_{r \in P^w} \delta_{ar} f_r^w, \sum_{r \in P^w} f_r^w = d_w, f_r^w \geq 0, d_w \geq 0, \forall w \in W, r \in P^w \right\}.$$

$$\begin{aligned}
\sum_{a \in A} \delta_{ar} (t_a(v_a) + l_a p) &= D_w^{-1}(d_w) && \forall r \in P_{++}^w(\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}), w \in W, \\
\sum_{a \in A} \delta_{ar} (t_a(v_a) + l_a p) &\geq D_w^{-1}(d_w) && \forall r \in P_0^w(\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}), w \in W, \\
\sum_{a \in A} l_a v_a &= K && \text{if } p > 0 \\
\sum_{a \in A} l_a v_a &\leq K && \text{if } p = 0
\end{aligned}$$

Analysis of Tradable Credits

- Mathematical program

$$\min \quad \sum_{a \in A} \int_0^{v_a} t_a(\omega) d\omega - \sum_{w \in W} \int_0^{d_w} D_w^{-1}(\omega) d\omega$$

$$s.t. \quad (\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}) \in V$$

$$\sum_{a \in A} l_a v_a \leq K \longleftarrow$$

The Lagrangian multiplier is the credit price, i.e., *p*

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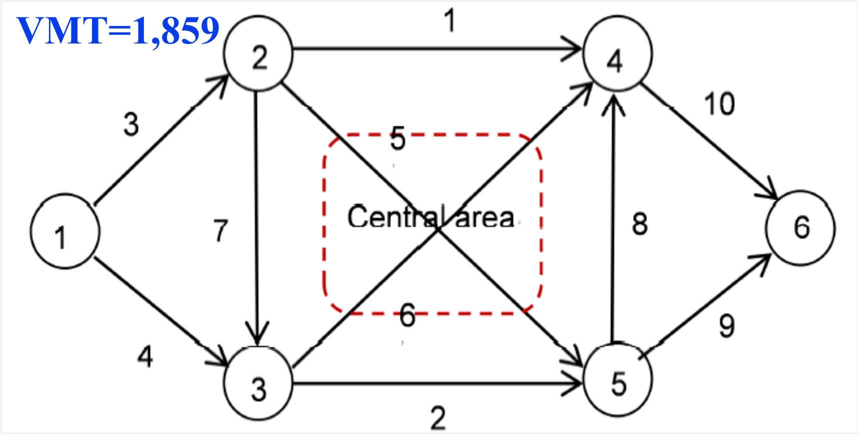

Analysis of Tradable Credits

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$$s.t.\quad (\boldsymbol{f},\boldsymbol{v},\boldsymbol{d}) \in V$$
$$\sum_{a\in A} l_a v_a \le K$$

← **The Lagrangian multiplier is the credit price, i.e., *p***

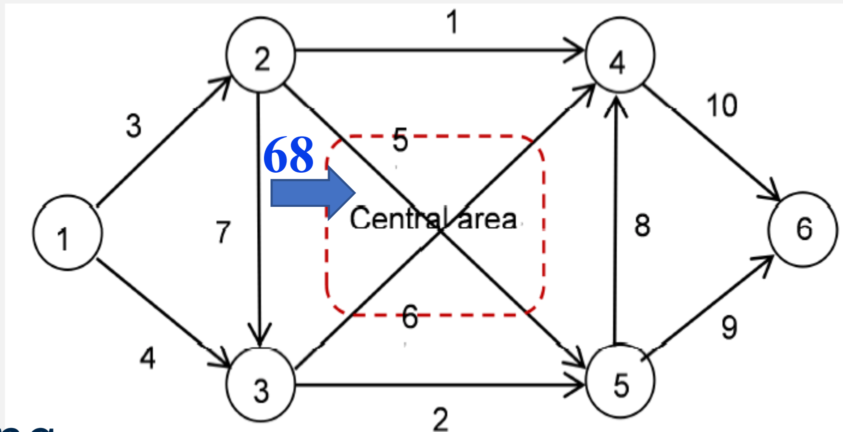
- Congestion pricing counterpart

$$\min \sum_{a\in A}\int_0^{v_a} s_a(\omega)d\omega - \sum_{w\in W}\int_0^{d_w} D_w^{-1}(\omega)d\omega + \sum_{a\in A} v_a l_a p$$
$$s.t.\quad (\boldsymbol{f},\boldsymbol{v},\boldsymbol{d}) \in V$$

Example

- Control objective
  - Reduce the number of vehicles into the central area to be less than 50
- Tradable credit scheme
  - Allocating 50 credits to travelers
  - Charging one credit for each vehicle entering
- Under idealized conditions, total trips entering the central area will be 50 and the market price of each credit is 6.055

$$D_{16}(u_{16}) = 500\exp(-0.05u_{16})$$



Analysis of Tradable Credits

- Equilibrium

$$p + \sum_{a \in A} \delta_{ar} s_a(v_a) = D_w^{-1}(d_w) \qquad \forall r \in TP_{++}^w(\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}), w \in W,$$

$$p + \sum_{a \in A} \delta_{ar} s_a(v_a) \geq D_w^{-1}(d_w) \qquad \forall r \in TP_0^w(\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}), w \in W,$$

$$\sum_{a \in A^2} \delta_{ar} s_a(v_a) = D_w^{-1}(d_w) \qquad \forall r \in NP_{++}^w(\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}), w \in W,$$

$$\sum_{a \in A^2} \delta_{ar} s_a(v_a) \geq D_w^{-1}(d_w) \qquad \forall r \in NP_0^w(\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}), w \in W,$$

$$\sum_w \sum_{r \in TP^w} f_r^w = K \qquad \text{if } p > 0$$

$$\sum_w \sum_{r \in TP^w} f_r^w \leq K \qquad \text{if } p = 0$$

- Mathematical program

$$\begin{aligned} \min \quad & \sum_{a \in A} \int_0^{v_a} s_a(\omega) d\omega - \sum_{w \in W} \int_0^{d_w} D_w^{-1}(\omega) d\omega \\ s.t. \quad & (\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}) \in V \\ & \sum_w \sum_{r \in TP^w} f_r^w \leq K \quad \longleftarrow \end{aligned}$$

The Lagrangian multiplier is the credit price, i.e., *p*

Congestion Pricing Counterpart

$$\min \sum_{a \in A} \int_0^{v_a} s_a(\omega) d\omega - \sum_{w \in W} \int_0^{d_w} D_w^{-1}(\omega) d\omega + \sum_{w} \sum_{r \in TP^w} f_r^w p$$

$$s.t. \quad (\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}) \in V$$

$$V = \left\{ (\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}) : v_a = \sum_{w} \sum_{r \in P^w} \delta_{ar} f_r^w, \sum_{r \in P^w} f_r^w = d_w, f_r^w \geq 0, d_w \geq 0, \forall w \in W, r \in P^w \right\}.$$

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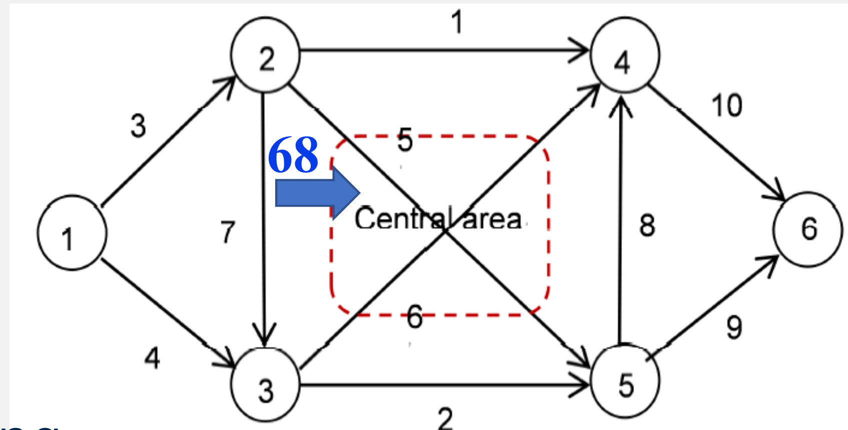
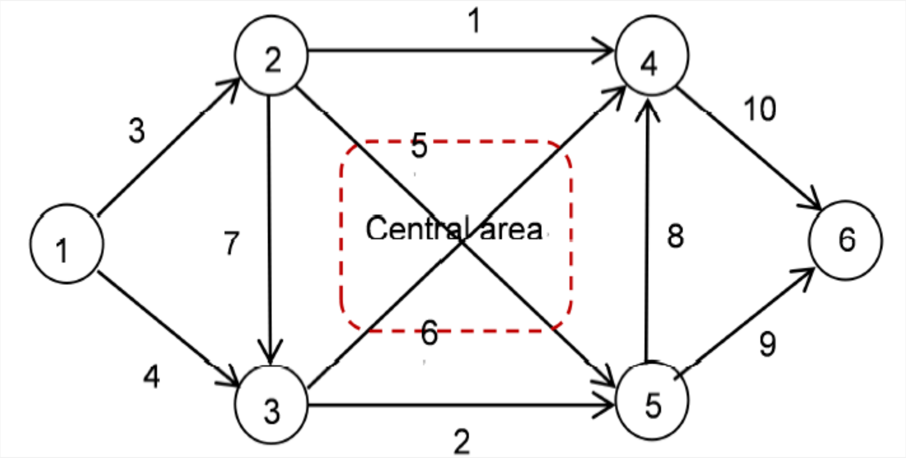


Social Benefit Maximization



The government agency need to allocate 1523 credits to all eligible travelers and then charge 5.002, 6.577, 4.739, 3.957, 4.995, 5.784, 0.018, 0.007, 4.745 and 3.951 credits respectively at links 1 to 10. The market credit price is 1.

Link-level Congestion as Control Target

- Design of Tradable Credit or Pricing Scheme

$$
\begin{aligned}
\min \quad & \sum_{a \in A} \int_0^{v_a} s_a(\omega) d\omega - \sum_{w \in W} \int_0^{d_w} D_w^{-1}(\omega) d\omega \\
s.t. \quad & (\boldsymbol{f}, \boldsymbol{v}, \boldsymbol{d}) \in V \\
& v_a \leq \hat{v}_a \qquad\qquad a \in A
\end{aligned}
$$

The Lagrangian multiplier is τ_a

- The traffic authority needs to allocate $K = \sum_{a \in A} \tau_a v_a$ to eligible travelers and then collect τ_a credits for traveling on link a. With such a scheme, the market-clearing credit price is 1.

Analysis of Tradable Credits

- Equilibrium

$$\sum_{a\in A}\delta_{ar}(s_a(v_a)+\tau_a p) \ = D_w^{-1}(d_w) \qquad \forall r\in P_{++}^w(\boldsymbol{f},\boldsymbol{v},\boldsymbol{d}), w\in W$$

$$\sum_{a\in A}\delta_{ar}(s_a(v_a)+\tau_a p) \ \geq D_w^{-1}(d_w) \qquad \forall r\in P_0^w(\boldsymbol{f},\boldsymbol{v},\boldsymbol{d}), w\in W$$

$$\sum_{a\in A}\tau_a v_a = K \qquad \text{if } p>0$$

$$\sum_{a\in A}\tau_a v_a \leq K \qquad \text{if } p=0$$

- Mathematical program

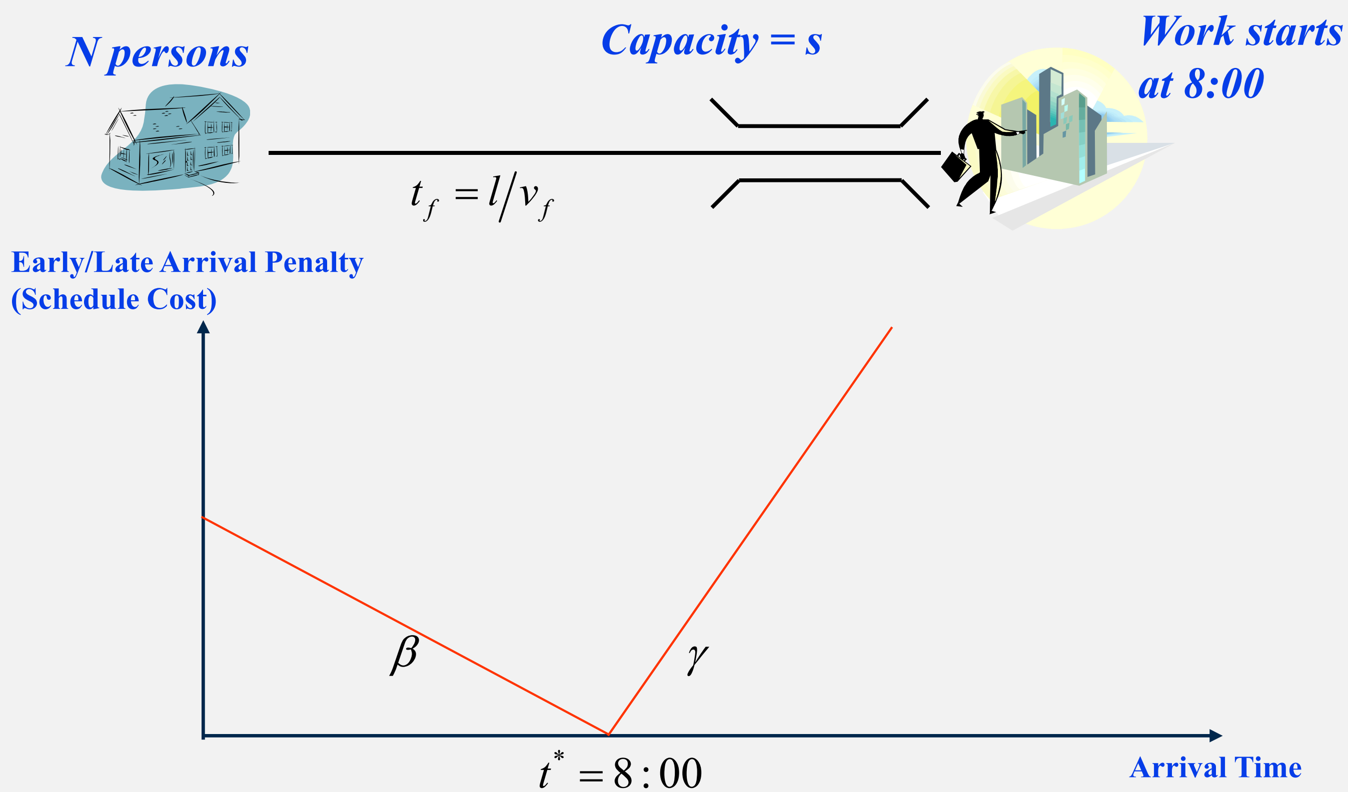
$$\min \sum_{a\in A}\int_0^{v_a} s_a(\omega)d\omega - \sum_{w\in W}\int_0^{d_w} D_w^{-1}(\omega)d\omega$$

$$s.t. \ \ (\boldsymbol{f},\boldsymbol{v},\boldsymbol{d})\in V$$

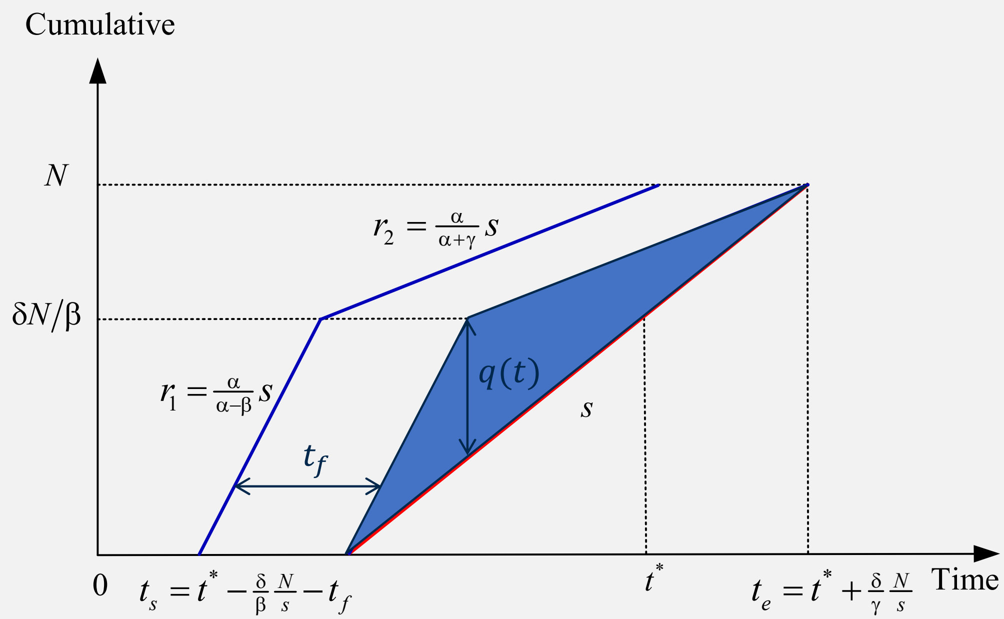
$$\sum_{a\in A}\tau_a v_a \leq K$$

The Lagrangian multiplier is the credit price, i.e., *p*

Morning Commute



Departure/Arrival Patterns

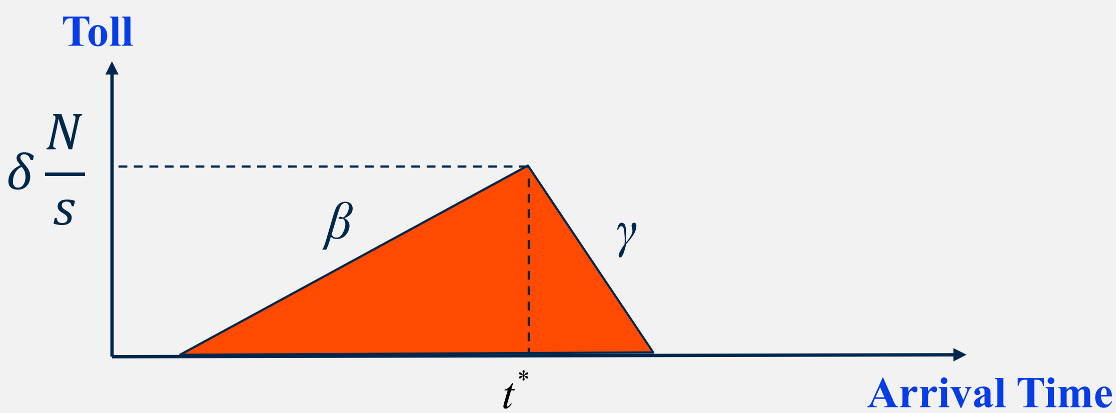


Equilibrium individual travel cost: $c(N) = \alpha t_f + \delta \frac{N}{s}$

$$\delta = \beta\gamma / (\beta + \gamma)$$

Tradable Credit vs. Congestion Pricing

- Congestion Pricing (Vickery,1969)



- Tradable Credits

  Distribute $\frac{1}{2}\delta\frac{N^2}{s}$ credits to travelers; The credit price is one if the time-dependent credit charge is the same as above.

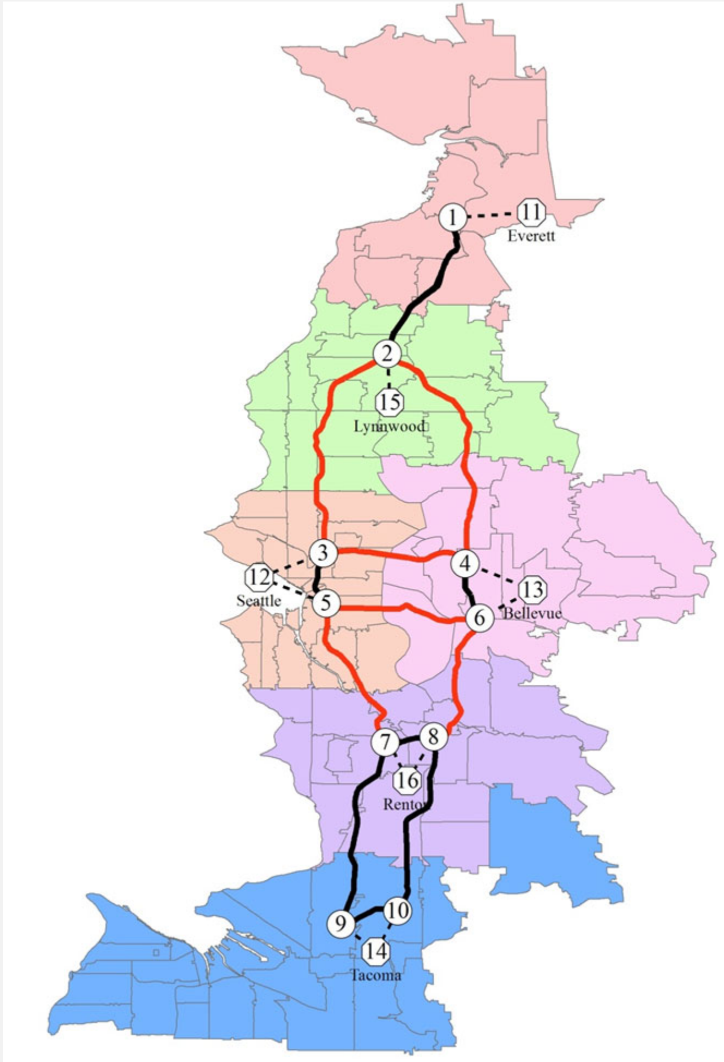
Why Tradable Credits?

- There is a one-to-one correspondence between congestion pricing and tradable credit schemes in managing network mobility (Weitzman, 1974)

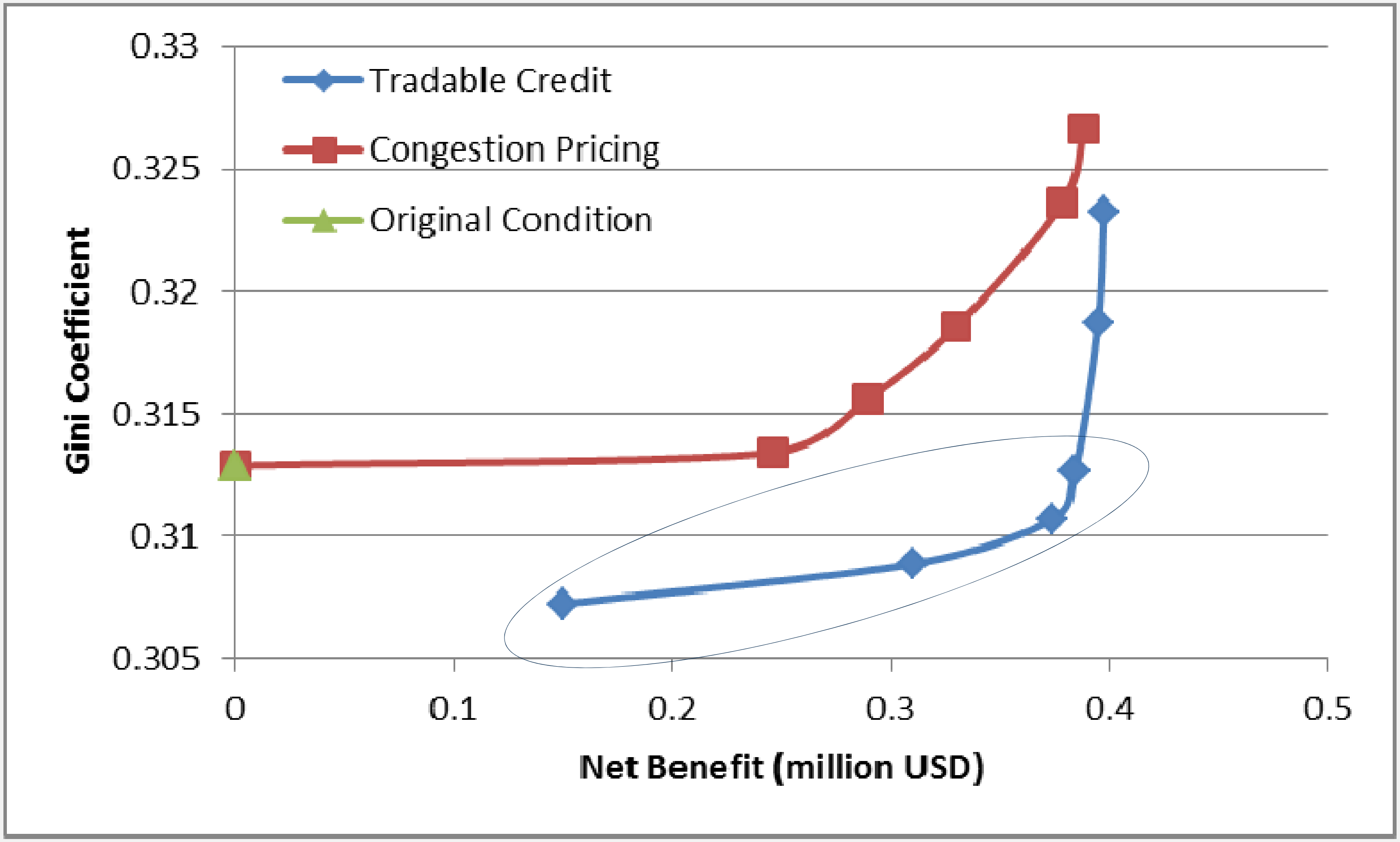
- Advantages of tradable credit schemes
  - Achieve a control target with causing minimum loss to travelers in an idealized environment
  - When justified, the welfare effects of the scheme on individuals may be controlled by the way the credits are distributed
  - The market allows those who value travel time savings less to be directly compensated by selling credits to those who value them more, thereby promising simpler and fairer distribution of the benefits from congestion reduction
  - More amenable to public acceptance

Numerical Example

- Credit schemes to improve the performance of the Seattle Regional Network (Transit and Freeway)
  - Origin-specific distribution: uniform distribution among travelers of the same origin; varying from origin to origin
  - Credit charges on both freeway and transit links, varying from link to link

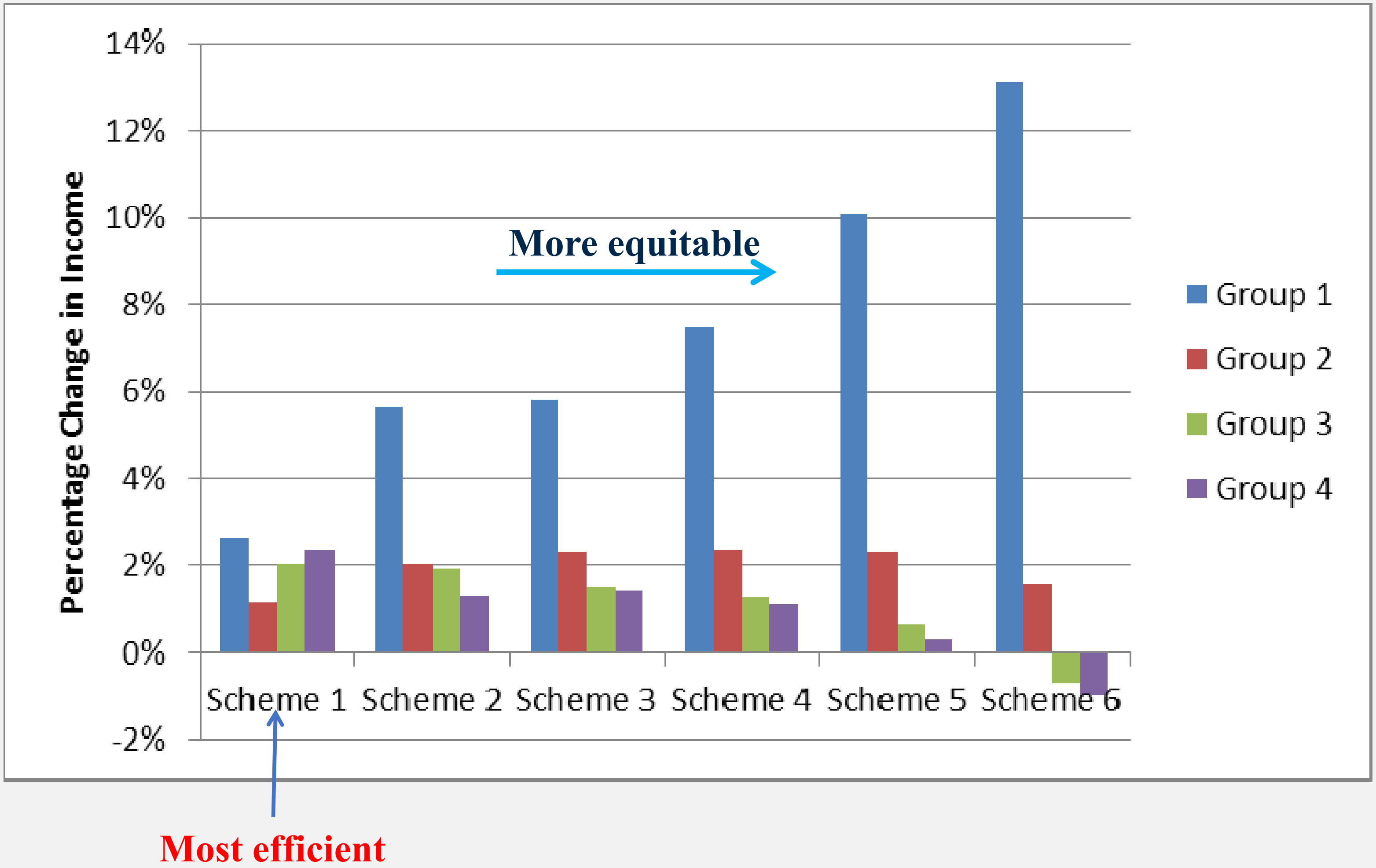


Comparison

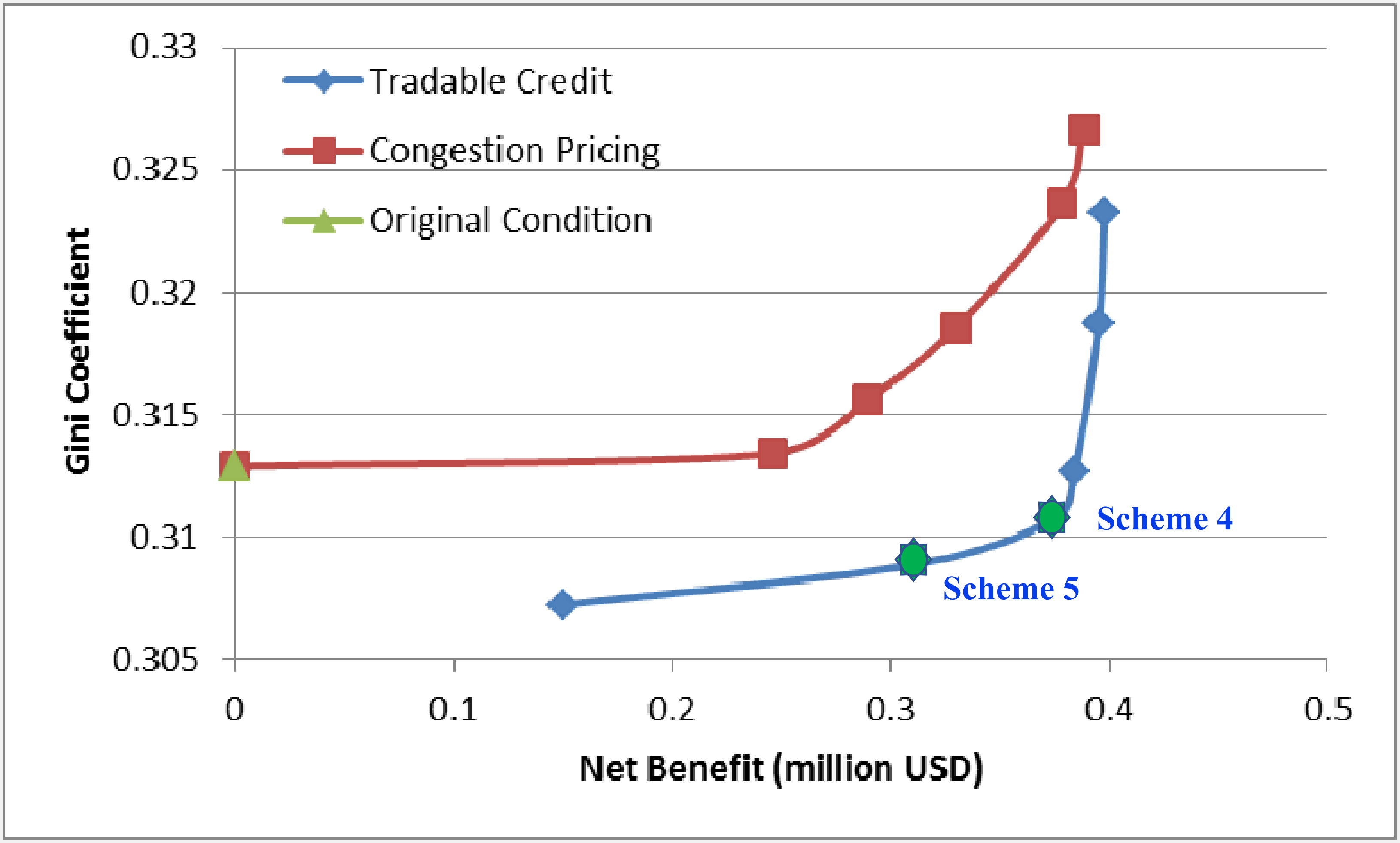


Tradable Credit
Congestion Pricing
Original Condition
Gini Coefficient
0.33
0.325
0.32
0.315
0.31
0.305
0
0.1
0.2
0.3
0.4
0.5
Net Benefit (million USD)

Benefit Distribution of Credits



Comparison



Tradable Credit
Congestion Pricing
Original Condition
Scheme 4
Scheme 5
Gini Coefficient
0.33
0.325
0.32
0.315
0.31
0.305
0
0.1
0.2
0.3
0.4
0.5
Net Benefit (million USD)

Observations

- Pareto improvement under the most efficient credit scheme.
  - Low-income travelers: selling extra credits
  - High-income travelers: reduction in driving time
- Better equity is achieved by increasing the number of credits charged at each link
  - More credits charged → more demand for credits → higher credit price → more subsidies

Outline

1 Equity concern of congestion pricing

2 Pricing design with explicit equity consideration

3 Tradable mobiltiy credits to address equity concerns

4 Concluding remarks

Concluding Remarks

- Income-based equity concern can be largely addressed by a well-designed pricing and revenue redistribution scheme
- A modeling framework is proposed to support the decision making
- A well-designed scheme will charge right prices at right locations and use the revenue wisely to subsidize transit
- Price differentiation or discrimination can further improve income-based equity
- Tradable credits scheme offers an efficient yet more equitable option for congestion mitigation. However, it has its own issues. For example, market frictions will make it less efficient than its pricing counterpart

Congestion Pricing in New York City

- NYC will soon implement the nation's first congestion pricing program
- According to the plan, cars will pay $15 to enter Manhattan below 60th Street once per day.
- To address income-based equity:
  - Low-income drivers will get 50 percent off tolls during the day after the first 10 trips in a calendar month.
  - Toll revenue (roughly $1 billion annually) will fund improvements to the city's subway and bus networks
- Study concludes the program "will not be a regressive surcharge on New Yorkers in poverty"*.

**https://www.cssny.org/news/entry/congestion-pricing-outer-borough-new-yorkers-poverty-data-analysis*

Reference papers

- Wu, D., Yin, Y., Lawphongpanich, S. and Yang H. Design of more equitable congestion pricing and tradable credit schemes for multimodal transportation Networks. Transportation Research Part B, 46(9), 1273-1287, 2012
- Shirmohammadi, N., Zangui, M., Yin, Y. and Nie, Y. Analysis and design of tradable credit schemes under uncertainty. Transportation Research Record, 2333, 27-36, 2013.
- Mamun, M.S., Michalaka, D., Yin, Y. and Lawphongpanich, S. Comparison of socioeconomic impacts of market-based instruments for mobility management, International Journal of Sustainable Transportation, 10 (2), 96-104, 2016
- Zangui, M., Yin, Y., Lawphongpanich, S. and Chen, S. Differentiated congestion pricing of urban transportation networks with vehicle-tracking technologies. Transportation Research Part C, Vol. 36, 434-445, 2013

Thank You

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