Why License Plate Rationing Does Not Work and How to Fix It?

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Introduction

Traffic congestion problem
Solutions

Model

Why not work?

Analysis
Numerical results

How to fix it?

LPR+NVQ
LPR+Trading with Auto Owners
Permit rationing and trading with all travelers

Conclusions
The traffic congestion problem

- Infamous symptoms of traffic congestion: lost time, disrupted schedules, wasted fuel, deteriorating air quality, and discomfort.
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- Costed urban Americans approximately $121 billion in 2012.
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- Costed urban Americans approximately $121 billion in 2012.
- A daunting challenge for the developing countries due to rapid urbanization.
### National Congestion Tables

**Table 1. What Congestion Means to You, 2011**

<table>
<thead>
<tr>
<th>Urban Area</th>
<th>Yearly Delay per Auto Commuter</th>
<th>Travel Time Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours</td>
<td>Rank</td>
</tr>
<tr>
<td>Very Large Average (15 areas)</td>
<td>52</td>
<td>1</td>
</tr>
<tr>
<td>Washington DC-VA-MD</td>
<td>67</td>
<td>1</td>
</tr>
<tr>
<td>Los Angeles-Long Beach-Santa Ana CA</td>
<td>61</td>
<td>2</td>
</tr>
<tr>
<td>San Francisco-Oakland CA</td>
<td>61</td>
<td>2</td>
</tr>
<tr>
<td>New York-Newark NY-NJ-CT</td>
<td>59</td>
<td>4</td>
</tr>
<tr>
<td>Boston MA-NH-RI</td>
<td>53</td>
<td>5</td>
</tr>
<tr>
<td>Houston TX</td>
<td>52</td>
<td>6</td>
</tr>
<tr>
<td>Atlanta GA</td>
<td>51</td>
<td>7</td>
</tr>
<tr>
<td>Chicago IL-IN</td>
<td>51</td>
<td>7</td>
</tr>
<tr>
<td>Philadelphia PA-NJ-DE-MD</td>
<td>48</td>
<td>9</td>
</tr>
<tr>
<td>Seattle WA</td>
<td>48</td>
<td>9</td>
</tr>
<tr>
<td>Miami FL</td>
<td>47</td>
<td>11</td>
</tr>
<tr>
<td>Dallas-Fort Worth-Arlington TX</td>
<td>45</td>
<td>13</td>
</tr>
<tr>
<td>Detroit MI</td>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td>San Diego CA</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>Phoenix-Mesa AZ</td>
<td>35</td>
<td>40</td>
</tr>
</tbody>
</table>

Very Large Urban Areas—over 3 million population.

Large Urban Areas—over 1 million and less than 3 million population.

Medium Urban Areas—over 500,000 population.

Small Urban Areas—less than 500,000 population.

Yearly Delay per Auto Commuter—Extra travel time during the year divided by the number of people who commute in private vehicles.

Travel Time Index—The ratio of travel time in the peak period to the travel time at free-flow conditions. A value of 1.30 indicates a peak period that is 30 percent longer than the free-flow condition.
Autonavi report: Top 10 most congested Chinese cities

2015 First Quarter

2015Q1 Most congested city TOP10

Beijing

Shanghai

2015Q1 中国主要城市交通分析报告

2015 Q1

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2015.1.1~2015.3.31

数据说明：
早高峰：07:00~09:00
晚高峰：17:00~19:00
全天：06:00~22:00

范围说明：
本报告覆盖全国114城市交通信息

排名说明：
目前，高德支持全国15个城市交通信息

1. 北京
2. 上海
3. 广州
4. 深圳
5. 天津
6. 哈尔滨
7. 郑州
8. 成都
9. 南宁
10. 重庆

(1) 2015Q1中国主要城市交通拥堵排名分布
The solutions

Increase supply: more roads, better management, new technologies (autonomous and connected vehicles very promising)

May face financial and physical limits.

May be self-defeating as it induces demand.

Manage demand: reduce total VMT by automobiles.

Sticks: pricing or rationing car ownership and/or use

Carrots: incentivizing efficient and green travel modes (sharing, walking, biking).
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The basic economic theory is compelling

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- If some drivers are "forced" out the fast road, the total travel time will be reduced.

Congestion pricing

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Why nobody likes it?

"Yet another tax!!!"
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Why nobody likes it?

- Successful stories of congestion pricing are limited to a handful of cities (Singapore, London, Stockholm)
- High-profile public rejections (Hong Kong, Edinburgh, New York)
- Politically too expensive even for very powerful governments.

"Yet another tax!!!"

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New vehicle quota: a low-hanging fruit?

Vehicle Quota System

- The Land Transport Authority (LTA) determined the no. of new motor vehicles allowed for registration.
New vehicle quota: a low-hanging fruit?

- VQS was first implemented in Singapore (New license plates were sold through auction)
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- Beijing 2010, license plates are distributed by lottery
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- Manila, Philippine (1996)
- Sao Paulo, Brazil (1997)
- Bogota, Columbia (2000)
- Beijing, China (2011)
- Chengdu, Tianjin, Hangzhou.... (since 2012)
Objectives

Appeal of LPR

- Easy to implement and enforce
- Revenue neutral
- Perceived as fair (since restrictions apply to all)
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- Revenue neutral
- Perceived as fair (since restrictions apply to all)

1. First, I will explain why LPR is a not a good policy
2. Second, I will propose and analyze a few alternative policies that retain these advantages of LPR as much as possible.
Model

Choice 2, Own two cars
auto capital cost = 2φ

Driving, travel time = τ, operating cost = cA

Choice 1: Own one car
auto capital cost = φ

β
F(β)

Value of Time
q

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Assumptions

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**Model**

Choice 0: Take transit, travel time = $\gamma$, operating cost = $cT$

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**Assumptions**

- The travel demand is fixed;
- Travelers choose between driving (with one or two cars) and taking transit based on travel cost;

The travel cost is represented as:

- $u_A = \beta \tau + cA + \phi$
- $u_T = \beta \gamma + cT$

Assumptions:

1. The travel demand is fixed;
2. Travelers choose between driving (with one or two cars) and taking transit based on travel cost;
3. Travelers are heterogeneous in their value of time $\beta$, which follows a continuous distribution;
4. One car is sufficient to meet travel needs (drivers would buy the second car only to avoid use restriction).
The travel cost is represented as

\[ u_A = \beta \tau(q) + c_A + \phi, \]
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Assumptions

- The travel demand is fixed;
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\[ q = \beta \left( F(\beta) \right) \]

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User equilibrium

Ignoring corner solutions, the equilibrium is achieved when $u_A = u_T$, i.e.

$$F^{-1}(q_e)\tau(q_e) + c_A + \phi = \gamma F^{-1}(q_e) + c_T.$$  

$$(\gamma - \tau(q_e))\beta_e = \Delta c$$

where $\beta_e = F^{-1}(q_e)$, $\Delta c = c_A + \phi - c_T > 0$
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\[
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\]

where \( \beta_e = F^{-1}(q_e) \), \( \Delta c = c_A + \phi - c_T > 0 \)

- Travelers with \( \beta > \beta_e \) will drive
- Travelers with \( \beta < \beta_e \) will ride transit.
The total system cost can be written as

\[
\hat{G} \equiv \int_0^q F^{-1}(w)\tau(q)dw + \int_q^d F^{-1}(w)\gamma dw + (c_A + \phi)q + c_T(d - q)
\]

The first-order optimality condition leads to

\[
\frac{d\hat{G}}{dq} = 0 \rightarrow (\gamma - \tau(q))F^{-1}(q) = \Delta c + \tau(q)' \int_0^q F^{-1}(w)dw
\]

If \(q_s\) is solution to the above equation, then the system optimal toll is

\[
\mu_s = \tau(q_s)' \int_0^{q_s} F^{-1}(w)dw
\]
Setting of LPR

Under LPR, all travelers with one car can only drive on a fraction of all days depending on the last digit of the license plate. This fraction is denoted as $\lambda \in [0, 1]$. 
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There are three choices: 0 (taking transit), 1 (owning one car), and 2 (owning two cars).
User equilibrium (UE) solutions

User cost

\[ u_1 = \lambda (\beta \tau(q) + c_A) + (1 - \lambda)(\beta \gamma + c_T) + \phi, \]
\[ u_2 = \beta \tau(q) + c_A + 2\phi, \]
\[ u_0 = \beta \gamma + c_T. \]

Also note that highway flow \( q = f_2 + \lambda f_1 \).

Characteristics of UE solutions

When \( \lambda \) is sufficiently close to 1, travelers will choose between taking transit and owning one car; when \( \lambda \) reaches a threshold \( \hat{\lambda} \), wealthy travelers will begin to acquire the second car. When \( \lambda \) is reduced to 0.5, all drivers would have two cars.
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System optimum (SO) solution

\[
\begin{align*}
\min \hat{G} &= \int_0^{f_2} F^{-1}(w)\tau(q)dw + (c_A + 2\phi)f_2 + \int_{f_2}^{f_1+f_2} F^{-1}(w)\left(\lambda\tau(q) + (1 - \lambda)\gamma\right)dw \\
&\quad + \lambda f_1(c_A + \phi) + (1 - \lambda)f_1(\phi + c_T) + \int_{f_1+f_2}^{d} F^{-1}(w)\gamma dw + c_T(d - f_1 - f_2) \\
\text{subject to:} & \quad f \in [0, d], \lambda \in [0, 1]
\end{align*}
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subject to: \(f \in [0, d], \lambda \in [0, 1]\)

\[
\frac{\partial \hat{G}}{\partial f_1} = \lambda F^{-1}(f_1 + f_2)(\tau(q) - \gamma) + \lambda \pi + \lambda \Delta c + (1 - \lambda)\phi
\]

\[
\frac{\partial \hat{G}}{\partial f_2} = (\lambda F^{-1}(f_1 + f_2) - (1 - \lambda)F^{-1}(f_2))(\tau(q) - \gamma) + \pi + \Delta c + \phi
\]

\[
\frac{\partial \hat{G}}{\partial \lambda} = \int_{f_2}^{f_1+f_2} F^{-1}(w)dw(\tau(q) - \gamma) + f_1 \pi + f_1(c_A - c_T),
\]

where

\[
\pi = \tau(q)'(\lambda \int_{f_2}^{f_1+f_2} F^{-1}(w)dw + \int_{f_2}^{f_2} F^{-1}(w)dw)
\]
Main result I: cost at UE

Proposition

Let $[f_1^a, f_2^a]$ and $[f_1^b, f_2^b]$ be UE solutions corresponding to $\lambda_a$ and $\lambda_b$. (1) If $1 \geq \lambda_a > \lambda_b \geq \hat{\lambda}$, $\tau(q^a) > \tau(q^b)$; and (2) If $\hat{\lambda} > \lambda_a > \lambda_b \geq 0.5$ and $f_1^a + f_2^a < f_1^b + f_2^b$, $\tau(q^a) > \tau(q^b)$. 

Implications

Highway travel time decreases with tighter rationing policies until travelers begin to buy the second car. A sufficient condition is that the share of transit mode must increase in response to a tighter rationing policy (a very strong condition) 

Unexpected result: $\tau$ may increase when $\lambda$ is reduced! 

The total system cost at UE MAY increase under LPR.
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\[f^a_1 + f^a_2 < f^b_1 + f^b_2, \ \tau(q^a) > \tau(q^b).\]

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- Unexpected result: \(\tau\) may increase when \(\lambda\) is reduced!
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Implications

- Highway travel time decreases with tighter rationing policies until travelers begin to buy the second car.
- A sufficient condition is that the share of transit mode must increase in response to a tighter rationing policy (a very strong condition).
- Unexpected result: \(\tau\) may increase when \(\lambda\) is reduced!
- The total system cost at UE MAY increase under LPR.
Main result II: cost at SO

**Proposition**

Let \([f^*, \lambda^*]\) be the solution to SO problem. Ignoring trivial corner solutions, \(\lambda^* = 1\).

For any given \(\lambda < 1\), the system cost can always be minimized with \(\lambda\) being treated as a parameter instead of a variable.

**Implications**
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- Proposition 2 asserts that the solutions for those parametric problems would be always inferior to that with \(\lambda = 1\).
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**Implications**

- Proposition 2 asserts that the solutions for those parametric problems would be always inferior to that with $\lambda = 1$.
- The total system cost will always increase at SO!
- Even if a first-best policy can be implemented, it cannot minimize the system cost under LPR.
Main result III: SO toll

Under LPR, to decentralize the SO we will need to charge one-car travelers a toll equal $\lambda \pi$ and two-car travelers a toll equal $\pi$, where

$$
\pi = \tau(q)'(\lambda \int_{f_2}^{f_1+f_2} F^{-1}(w) dw + \int_0^{f_2} F^{-1}(w) dw)
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Main result III: SO toll

SO toll under LPR

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$$\pi = \tau(q)'(\lambda \int_{f_2}^{f_1 + f_2} F^{-1}(w)\,dw + \int_{0}^{f_2} F^{-1}(w)\,dw)$$

- Those who opt to buy a second car need to pay an extra toll equal to $(1 - \lambda)\pi$
Main result III: SO toll

SO toll under LPR

Under LPR, to decentralize the SO we will need to charge one-car travelers a toll equal $\lambda \pi$ and two-car travelers a toll equal $\pi$, where

$$\pi = \tau(q)'(\lambda \int_{f_1+f_2}^{f_2} F^{-1}(w)dw + \int_0^{f_2} F^{-1}(w)dw)$$

- Those who opt to buy a second car need to pay an extra toll equal to $(1 - \lambda)\pi$
- This additional toll may be collected as an extra “sales tax” (or an additional registration fee) upon the purchase of the second car.
Under LPR, to decentralize the SO we will need to charge one-car travelers a toll equal to $\lambda \pi$ and two-car travelers a toll equal to $\pi$, where

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- Those who opt to buy a second car need to pay an extra toll equal to $(1 - \lambda)\pi$
- This additional toll may be collected as an extra “sales tax” (or an additional registration fee) upon the purchase of the second car.
- This SO toll is progressive.
Experimental setting

\[ \tau(q) = \tau_0 \left( 1 + 0.15 \left( \frac{q}{C} \right)^4 \right), \]
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\[ \tau(q) = \tau_0 \left( 1 + 0.15 \left( \frac{q}{C} \right)^4 \right), \]

\[ F(\beta) = \frac{d(\beta u - \beta)}{\rho\beta + \beta u}, \]

\( \rho \) is called the index of wealth.
Experimental setting

\[ \tau(q) = \tau_0 \left( 1 + 0.15 \left( \frac{q}{C} \right)^4 \right), \]

\[ F(\beta) = \frac{d(\beta_U - \beta)}{\rho \beta + \beta_U}, \]

- \( \rho = 0 \): a uniform distribution between 0 and \( \beta_U \)
- \( \rho \in (-1, 0) \), skewed to individuals with higher VOT
- \( \rho \in (1, \infty) \), skewed to individuals with lower VOT
Experimental setting

Table: Description of model parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Default value</th>
<th>Unit</th>
<th>Description</th>
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<tbody>
<tr>
<td>$\gamma$</td>
<td>1</td>
<td>hour</td>
<td>Transit travel time/trip</td>
</tr>
<tr>
<td>$c_T$</td>
<td>5</td>
<td>$</td>
<td>Transit operating cost/trip</td>
</tr>
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<td>$\tau_0$</td>
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<td>hour</td>
<td>Highway free flow travel time/trip</td>
</tr>
<tr>
<td>$C$</td>
<td>500</td>
<td>veh/hour</td>
<td>Highway capacity</td>
</tr>
<tr>
<td>$d$</td>
<td>1000</td>
<td>person</td>
<td>Total demand</td>
</tr>
<tr>
<td>$c_A$</td>
<td>6</td>
<td>$</td>
<td>Auto operating cost/trip</td>
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<tr>
<td>$\phi$</td>
<td>5</td>
<td>$</td>
<td>Auto capital cost/trip</td>
</tr>
<tr>
<td>$\beta_U$</td>
<td>60</td>
<td>$/hour</td>
<td>Highest VOT</td>
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<tr>
<td>$\rho$</td>
<td>0.1</td>
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Scenario D All parameters take default values.
Scenario P All parameters take default values except $\rho = 4$ (poor population)
Scenario R All parameters take default values except $\rho = -0.6$ (rich population)
Scenario L All parameters take default values except $\phi = 2.5$ (low auto capital cost)
Scenario H All parameters take default values except $\rho = 10$ (high auto capital cost)
Default scenario

Drivers begin to buy the second car

- **Rationing ratio ($\lambda$)**
- **Flow**
  - $f_1$ (UE)
  - $f_2$ (UE)
  - $f_1$ (SO)
  - $f_2$ (SO)

- **Total cost ($\$$)**
  - **UE cost**
  - **SO Cost**

- **Average highway travel time (hour)**
  - **UE Time**
  - **SO Time**

Drivers begin to buy the second car at a rationing ratio of approximately 0.8. This triggers changes in the flow, total cost, and average highway travel time, indicating a shift in the demand for second cars and the associated impacts on the system.
Default scenario

- **Model**
  - Why not work?
  - How to fix it?
  - Conclusions
  - References

**Default scenario**

- **Rationing ratio (λ)**
  - Flow
    - \( f_1 (\text{UE}) \)
    - \( f_2 (\text{UE}) \)
    - \( f_1 (\text{SO}) \)
    - \( f_2 (\text{SO}) \)

- **Total cost ($)**
  - UE cost
  - SO Cost

- **Average highway travel time (hour)**
  - UE Time
  - SO Time

**Graphs**

- Graph 1: Flow vs. Rationing ratio (λ)
  - CarPop (UE)
  - HighwayFlow (UE)
  - CarPop(SO)
  - HighwayFlow(SO)

- Graph 2: Total cost ($) vs. Rationing ratio (λ)
  - UE cost first decreases, then increases
  - SO cost always increases

- Graph 3: Average highway travel time (hour) vs. Rationing ratio (λ)
  - UE Time
  - SO Time

**Legend**

- Blue: UE
- Red: SO
Default scenario

Total number of cars keeps increasing, and it increases at much higher pace when the second car purchase kicks in.
At UE, LPR is effective in reducing driving time until drivers begin to bypass the policy by buying the second car.
Welfare effects: cost increases compared to UE

Tranist users: LPR has no effects on them per our assumptions
Welfare effects: cost increases compared to UE

Low restriction, drivers benefit from the policy. Rich drivers benefit more.

High restriction, LPR forces more drivers to buy the second car, causing them to suffer welfare loss.

Users forced to give up their cars.
The total number of cars is higher for the richer population.

The highway flow is higher for the richer population.
The difference between SO and UE diminishes as the population becomes poorer.

Highway travel increases as $\lambda$ becomes more restrictive, for the rich population.
Proposed strategies

The key is to encourage travelers to cope with the restriction by switching to transit, not by getting the second car.

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LPR coupled with trading among auto owners

Inspired by the recent studies on tradable credit schemes (TCS), desirable access to driving may be achieved at a lower cost by purchasing permits than another car.

Permit rationing and trading among all travelers

Avoid making the right to drive as a de facto "entitlement" of auto owners.
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New vehicle quota (NVQ)

Recall

\[
\begin{align*}
    u_1(\beta) &= \lambda(\beta \tau(q) + c_A) + (1 - \lambda)(\beta \gamma + c_T) + \phi, \\
    u_2(\beta) &= \beta \tau(q) + c_A + 2\phi, \\
    u_0(\beta) &= \beta \gamma + c_T.
\end{align*}
\]

The NVQ scheme will introduce the following constraint:

\[
f_1 + 2f_2 \leq K_0 f_e
\]

where \( K_0 \geq 1 \) is the desired vehicle control target and \( f_e \) is the UE flow when \( \lambda = 1.0 \).
Let $\nu$ be the multiplier associated with the capacity constraints, the complementarity requires

$$\nu \geq 0; \nu(f_1 + 2f_2 - K_0 f_e) = 0$$

The UE conditions that incorporate this complementarity condition are

$$f_1 \in (0, d) \rightarrow \exists \beta_1 \in [\beta_L, \beta_U], s.t. \quad u_1(\beta_1) + \nu = u_0(\beta_1)$$
$$f_2 > 0 \rightarrow \exists \beta_2 \in [\beta_L, \beta_U], s.t. \quad u_1(\beta_2) + \nu = u_2(\beta_2) + 2\nu$$
Model trading with auto owners (TAO)

rationale

- Buying another vehicle to gain more access to the highway could be more expensive than acquiring permits
- Facilitate efficient allocation of permits among auto owners
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- Permit no longer tied to license plates
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- Permits can then be traded in a virtual market and linked to registered vehicles through an on-board unit.
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**Implementation issues**
- Permit no longer tied to license plates
- Virtual permits must be used.
- Permits can then be traded in a virtual market and linked to registered vehicles through an on-board unit.
- Transaction and enforcement may be done via vehicle-to-infrastructure (V2I) communication.
Travelers face four choices: transit (0), own one car and sell permits (1-), own one car and buy permits (1+), and own two cars and sell extra permits (2).
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\[ u_{1+}(\beta) = (\lambda + \delta(\beta)) (\beta \tau + c_A) + (1 - \lambda - \delta(\beta)) (\beta \gamma + c_T) + \phi + \delta(\beta) P \]
\[ u_{1-}(\beta) = (\lambda - \delta(\beta)) (\beta \tau + c_A) + (1 - \lambda + \delta) (\beta \gamma + c_T) + \phi - \delta(\beta) P \]
\[ u_2(\beta) = \beta \tau + c_A + 2\phi - P \delta(\beta) \]
\[ u_0(\beta) = \beta \gamma + c_T \]

where \( P \) is the price of permits required to gain full driving access.
A traveler may purchase or sell certain amount of permits, which is assumed to be a function of $\beta$, denoted as $\delta(\beta)$.

\[
\beta^* = F^{-1}(f_2 + f_{1+}) \\
\beta_1 = F^{-1}(f_2 + f_1) \\
\beta_2 = F^{-1}(f_2); f_1 = f_{1+} + f_{1-}
\]
A traveler may purchase or sell certain amount of permits, which is assumed to be a function of $\beta$, denoted as $\delta(\beta)$.

Consider two travelers $a$ and $b$, each with a VOT $\beta_a$ and $\beta_b$ such that $\beta_a > \beta_b$ and permits $\lambda_a, \lambda_b \in (0, 1)$. Traveler $a$ would always gain more than what traveler $b$ would lose if $\epsilon \in (0, \min(\lambda_b, 1 - \lambda_a))$ permit is transferred from $b$ to $a$.

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**Lemma**

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- Trading will always occur when $\lambda$ is restricted below 1.
- Since trading is mutually beneficial, the permit price must be positive.
Main result: characteristics of the trading function

**Proposition**

If \( \lambda \in [0.5, 1] \) and \( \beta_1 < \beta^* < \beta_2 < \beta_U \), then at user equilibrium, the permit trading function

\[
\delta(\beta) = \begin{cases} 
1 - 2\lambda & \beta \in [\beta_2, \beta_U] \\
1 - \lambda & \beta \in [\beta^*, \beta_2) \\
-\lambda & \beta \in [\beta_1, \beta^*) 
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\end{cases}$$

The amount of permits traded jumps abruptly, and its change coincides with the change in the primary travel choices.
Main results: characteristics of UE solution

- As $\lambda$ decreases from 1, relatively rich one-car travelers will begin to buy permits from their relatively poor peers.
Main results: characteristics of UE solution

- As $\lambda$ decreases from 1, relatively rich one-car travelers will begin to buy permits from their relatively poor peers.
- As $\lambda$ becomes more restrictive, the permit will become more valuable, and more zero-car travelers will become permit suppliers.
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- As $\lambda$ decreases from 1, relatively rich one-car travelers will begin to buy permits from their relatively poor peers.
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- When very restrictive $\lambda$ drives the demand for permits sufficiently high, the richest travelers may begin to acquire the second automobile to increase the permit supply.
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The UE solution may be summarized as follows.
- When $\lambda \in [\max(0.5, \hat{\lambda}), 1)$, travelers may choose policy 0, 1+ or 1−, but not 2.
- When $\lambda \in [0.5, \max(0.5, \hat{\lambda})]$, travelers may choose policy 1+, 1− or 2, but not 0.

where $\hat{\lambda}$ is the threshold where travelers begin to acquire the second car.
Enabling permit trading may initially motivate more travelers to become car owners.
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For a restrictive LPR, all travelers would choose to own at least one vehicle.
Summary

- Enabling permit trading may initially motivate more travelers to become car owners.
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- There would be many who own cars but never use them - a waste of social resources.
Enabling permit trading may initially motivate more travelers to become car owners.

For a restrictive LPR, all travelers would choose to own at least one vehicle.

There would be many who own cars but never use them - a waste of social resources.

The overall effectiveness of the policy is questionable.
Permit rationing and trading with all travelers (PRA-TAT)

- Distribute all driving permits evenly among all travelers.
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- Distribute all driving permits evenly among all travelers.
- The authority decides the percentage of eligible travelers who will be allowed to drive, also called $\lambda$.
- A hybrid of LPR and tradable credit scheme (TCS).
- Permits are given to travelers, not to vehicles, so no incentive to buy extra vehicles.
Three choices: use transit and sell all permits to auto owners (0), own one car and sell portion of the permit to other car owners (1-), and own one-car and buy options (1+).
**Main result**

\[
\delta(\beta) = \begin{cases} 
1 - \lambda & \beta \in [\beta_1, \beta_U] \\
-\lambda & \beta \in [\beta_L, \beta_1]
\end{cases}
\]

(3) For target highway flow \( q_0 \), driving restriction \( \lambda = q_0 / d \); and (4) the permit price \( P = \phi / \lambda \).

\[
\beta_1 = F^{-1}(f_{1+} + f_{1-}), \beta^* = F^{-1}(f_{1+}).
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Proposition

With the proposed PRA-TAT scheme, (1) no traveler would choose to own a car but sell permits at UE, i.e., \( f_{1-} = 0 \). (2) One-car travelers must purchase \( 1 - \lambda \) permit at UE, i.e.,

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- Permit trading in PRA-TAT leads to a surprisingly simple equilibrium solution!
- Trading behavior is defined by auto ownership, independent of user heterogeneity.
Each NVQ policy effectively restricts the total number of automobiles at the level dictated by $K_0$.

When the shadow cost is excluded, LPR-NVQ improve the system cost.

With the shadow cost, the system costs under LPR-NVQ becomes worse.
Higher auto capital cost leads to lower auto ownership.

Low auto capital cost leads to high shadow price.

With shadow price, the system is better off with high auto capacity cost!
LPR-TAO: Result

Trading leads to more one-car owners

Number of cars

System cost

Trading leads to more one-car owners

Nie
LPR-TAO: Result

Trading leads to less two-car owners

System cost

Number of cars

Nie LPR
LPR-TAO: Result

Trading leads to high car ownership initially, but it helps reduce ownership for restrictive LPR
LPR-TAO: Result

Trading increases the total system cost in most cases.
LPR-TAO: Sensitivity to auto capital cost

(a) Number of cars

Low auto capital cost increases ownership

(b) Zero-car travelers

Low capital cost improves system cost for higher restriction.

(c) System cost ($)

Congestion is worse with low capital cost

(d) Highway travel time (hours)
LPR-TAO: Sensitivity to auto capital cost

\[ \text{Price} = \frac{\phi}{\lambda} \]

Trading volume peaks when travelers begin to buy the second car.

Trading is more active when auto capital cost is lower.
At SO, about 44% travelers should use highway. So $\lambda = 0.44$

Permit price increases from zero to the value of SO toll.
LPR-TAO benefits the travelers with high value of time at the expense of those with medium value of time.

Under PRA-TAT all travelers benefit (Pareto-improving), though the benefits of “middle class” are the lowest.

Equity issue generally is worse when rationing is more restrictive.
Benefits of both policies are improved with a rich population
Welfare effects of LPR-TAO vs. PRA-TAT

Poor population

- Benefits of both policies are worsened with a poor population
- Even PRA-TAT does not achieve Pareto-improving.
- Whether or not such a policy is effective depends on the distribution of VOT.
Summary of findings

Shortcomings

- LPR is neither first-best nor second-best.

Possible solutions

- LPR-NVQ can improve "nominal" social welfare; but with shadow cost, it worsens the system cost.
- Allowing auto owners to trade their permit to drive is generally a worse policy than LPR itself.
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A revenue-neutral first-best policy with our assumptions can be introduced as an amendment in cities where LPR is already in place.
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- The policy may lead to unintended consequences (higher car ownership and worse congestion).

Possible solutions

- LPR-NVQ can improve “nominal” social welfare; but with shadow cost, it worsens the system cost.
- Allowing auto owners to trade their permit to drive is generally a worse policy than LPR itself.
- Allowing all travelers to trade permits is more efficient than other alternatives.
  - A revenue-neutral first-best policy with our assumptions.
  - can be introduced as an amendment in cities where LPR is already in place.
Future studies

- Generalize the analysis to determine the optimal control target in PRA-TAT in real-world applications
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- Validating the trading behavioral with day-to-day dynamics models or agent-simulation model
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- Generalize the analysis to determine the optimal control target in PRA-TAT in real-world applications
- Validating the trading behavioral with day-to-day dynamics models or agent-simulation model
- Combine PRA-TAT with other TDM policies, e.g. NVQ (many cities have both)...
- Implementation issues?
Thank you!
Questions and comments?

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Related publications


