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Tradable Travel Credit Schemes for Network Mobility Management

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Outline of Presentation

- Introduction to current network mobility management strategies
- Introduction to tradable travel credit schemes
- Model and properties of network traffic equilibria under tradable credit schemes
- Recently published and ongoing studies
Pricing and Quantity Instruments for Network Mobility Management

- **Pricing Instrument**
  - Efficient utilization of limited network resources
  - Inequality problem etc. → public opposition

- **Quantity Instrument**
  - Road space rationing
  - Tradable travel credit scheme
Road Space Rationing (e.g., Beijing)

- Restrict private cars’ access to roads on a uniform fraction of days.
- Effective (short-term).
- More equitable (?)
- Low efficiency (spatially and temporally).
- Long-run policy may lead to a sharp increase of old, cheap and high-polluting second-car consumption (negative impact to the environment).
Tradable Travel Credit Schemes Proposed by Yang and Wang (2011)

Introduction to Tradable Travel Credit Schemes for Managing Network Mobility

- Each participating agent receives a proportion of credits (on a periodic basis such as a month or a quarter)
  - Equity
- Initial distribution for free
  - Revenue-neutral incentives for mobility and environmental quality
- Credit charging scheme
  - Link-specific or cordon-based; distance or time-based; time-invariant or time-varying
Qualitative Properties of Tradable Travel Credit Schemes

- A policy target in terms of fix-quantity travel credits can be easily achieved.

Example: Distance-based credit charge for achieving control of total veh-km traveled on the network
The equilibrium price of credits is determined by the market through free trading.

- Market driven
- Credit flow from the higher income groups to the lower; the flow of money from the wealthy to the less.
- Enhance income distribution or financial transfer confined only to within the predefined group of travelers:
Mathematical Model of Traffic Equilibrium under Tradable Travel Credit Schemes

Equivalent model formulation:

\[
\min_{(v,f) \in \Omega} \sum_a \int_0^{v_a} t_a(\omega) \, d\omega
\]

subject to:

\[
v_a = \sum_{w \in W} \sum_{r \in R_w} f_{r,w} \delta_{a,r}, \quad a \in A
\]

\[
\sum_{r \in R_w} f_{r,w} = d_w, \quad w \in W
\]

\[
\sum_{a \in A} \kappa_a v_a \leq K
\]

\[
f_{r,w} \geq 0, \quad r \in R_w, w \in W
\]

First-order optimality conditions:

\[
\left( \sum_{a \in A} (t_a(v_a^*) + p\kappa_a) \delta_{a,r} - \mu_w \right) f_{r,w}^* = 0, \quad r \in R_w, w \in W
\]

\[
\sum_{a \in A} (t_a(v_a^*) + p\kappa_a) \delta_{a,r} - \mu_w \geq 0, \quad r \in R_w, w \in W
\]

\[
f_{r,w}^* \geq 0, \quad r \in R_w, w \in W
\]

\[
\left( \sum_a \kappa_a v_a^* - K \right) p = 0
\]

\[
\sum_{a} \kappa_a v_a^* \leq K
\]

\[
p \geq 0
\]

Equivalent traffic equilibrium and credit market equilibrium conditions
Theoretical Properties of Tradable Travel Credit Schemes

- For a given credit scheme, a unique equilibrium flow pattern exists; the equilibrium credit price is unique subject only to very mild assumptions.

**Proposition 1.** Given a tradable credit scheme \((K, \kappa) \in \Psi\), the credit price \(p^*\) at equilibrium is unique if there exists at least one O-D pair whose equilibrium path set always contains the same two (or more) paths with different credit charges.
A properly designed tradable credit scheme can emulate a congestion pricing system and support various desirable traffic flow optima:

- Social optimum
- Capacity-constrained traffic flow pattern
- Pareto-improving and revenue-neutral

**Proposition 3.** Given an SO credit charging scheme, \( \kappa^{so} \), and a total amount of credits issued, \( K^{so} = \sum_{a \in A} \kappa_a^{so} v_a^{so} \), if the credit price \( p^* \) at market equilibrium is unique and the total system travel time at SO is strictly less than that at UE without any policy intervention, then there exists an O-D based credit distribution scheme that can make every traveler strictly better off.
Traffic Equilibrium and Market Equilibrium with Tradable Credits: An Example

Link travel time: \( t_1 (v_1) = 8 + 2v_1, \quad t_2 (v_2) = 16 + v_2 \)

O-D demand: \( d_{1 \rightarrow 2} = 10, \)

Initial credit allocation: \( K = 30, \quad k_{1 \rightarrow 2} = 3 \)

Link credit charge: \( \kappa_1 = 4, \quad \kappa_2 = 2. \)

User equilibrium and credit market equilibrium conditions:

\[
8 + 2v_1 + 4p = 16 + v_2 + 2p \\
v_1 + v_2 = 10 \\
4v_1 + 2v_2 = 30
\]

A unique equilibrium solution:

Link flow: \( v_1^* = v_2^* = 5 \)

Link travel time: \( t_1^* = 18, \quad t_2^* = 21 \)

Unit credit price: \( p^* = 1.5 \)
Subsequent Recent Studies after Yang and Wang (2011)
Tradable Parking Permits for Improving Travel Efficiency

- Morning commuters often choose their departure times not only to trade off bottleneck congestion and schedule delays, but also in order to secure a parking spot due to limited parking spaces.

- Parking permit scheme to eliminate the external cost arising from the competition for parking spots.

- Free trading of parking permits among commuters to better cater for commuters’ parking needs.

Implementation Issue under Limited Information

- Analytical demand functions tailored for traffic demand control are difficult to establish in practice.
- A fundamental question: how to design the optimal credit scheme in a simple yet practical manner?

Trial-and error implementation of marginal cost pricing and tradable credit scheme
Implementation Issue under Limited Information

- Available information: observed flow; revealed credit price.
- The revealed credit price signalizes the necessity for an upward or downward adjustment of the total amount of credits to be issued in a subsequent implementation period.
- The observed road flow can be utilized to adjust cred charge.


Impacts of Transaction costs

- In the absence of transaction cost, traffic equilibrium and market equilibrium are independent of initial credit allocations.
- Nie (2012) incorporated transaction costs into the tradable credit scheme and model set up by Yang and Wang (2011)
- Looked into the impacts of transaction costs on traffic and market equilibrium and the system efficiency.

Income Effects

- The initial endowment of travel credits as part of traveler’s income (measured by the market value of the credits or the number of credits allocated to each traveler multiplied by their market price).

- Incorporated income effects into the analysis, modeling and evaluation of the tradable credit scheme within the framework of multimodal transportation networks.

Impacts of User Heterogeneity

- Heterogeneous users with discrete or continuous value of travel time distribution.
- Credits freely traded not only among travelers on different paths and origin-destination pairs, but also among travelers with different incomes or values of travel time.


Managing Bottleneck Congestion with a new Tradable Credit Scheme

- No commuter is entitled to receive credits through an allocation process; rather they have to earn the credits by traveling outside of a peak time window specified by the government agency.

- Commuters can also earn credits by switching to an alternative uncongested route/mode.

- Time-dependent credit charge during the peak time window.

Managing Bottleneck Congestion and Mode Choice

- Tradable travel credit scheme for managing bottleneck congestion and modal split in a competitive highway/transit network.
- Pareto-improving system optimum can be achieved to make all commuters better off.


How the traffic flow and credit price will impact each other and evolve together.

Travelers’ learning behavior of route choice based on their perceived path travel cost and credit price and cost.

Price adjustment rule according to the fluctuation of credit demand and supply.

Mixed Equilibrium Behaviors

- Deal with not only individual travelers (Wardrop-equilibrium players) but also transportation firms, such as logistic companies and transit agencies Cournot-Nash players.

- In the absence of transaction costs, anonymous credit schemes can be designed to decentralize the system optimum flow link pattern.

- Transaction costs affect the trading and route-choice behaviors of both Cournot-Nash and Wardrop-equilibrium players.

- Transaction costs may reduce the efficiency of those optimal credit schemes.

Design Issue

- Incorporate a tradable credit scheme into network design problems
- Incorporate equity constraints for travelers travelling from different origins to different destinations.
- Bi-level programing model and solution algorithm.

Summary

- Tradable credit scheme plays essentially the same role as road pricing in the regulation of congestion and environmental externalities, but addresses the social and political concerns of congestion charges:
  - Guarantee a predefined quantitative target to be attained;
  - Avoid unfairness and thus enhance political acceptability;
  - Make everyone better off and make less uneven income distribution through free credit allocation and trading;
  - Revenue-neutral.

Tradable credit scheme thus offers the best combination of cost-effectiveness, administrative flexibility and distributional fairness!