Overview of Dissertation

Main Theme:
Analysis of Public-Private Partnerships in Transportation Infrastructure Investment and Management

1) Effect of taxes and cost structure on transit investment viability
   Investigated the role of tax and cost structure in transit system investment, and indicated the importance of timing of decision making for the government

2) Capacity investment and pricing strategies on highway systems
   Investigated the role of ownership regime and network structure in highway system management, and provided the impacts of capacity and pricing strategies
Two Types of Governments

Proactive Government is effective in motivating private investment is because the commitment is made before each decision so that the concessionaire is convinced that no deviation is going to happen.

Timing of labor tax does not impact the decision making process.
More parties make it trickier

- With more parties involved in the game, government needs to take more initiative at the very beginning.
  Not only investment tax, but also labor tax comes into play during the process.
Non-benevolent government case

- When a government is partial to concessionaires, it actually helps to achieve the desired equilibrium. ($\lambda$ is the benevolent level).

- However, when the non-benevolent level is too high, concessionaire would indeed receive preferential benefits and service providers would be hurt.
Quick Summary

- More parties involvement requires more initiatives from government
- Non-benevolent government can be effective to certain extent
- Cost structure can further change the game (in short)\(^{(1)}\)

<table>
<thead>
<tr>
<th>Type</th>
<th>2 Party Game</th>
<th>3 Party Game</th>
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<tbody>
<tr>
<td>Proactive Government</td>
<td>Successful to maintain Ramsey Policy</td>
<td>Have to decide both (\Theta) and (T) before 1st Stage to maintain Ramsey Policy</td>
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<tr>
<td>(Decide (\Theta) before 1st Stage</td>
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<tr>
<td>Decide (T) before 2nd Stage)</td>
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<tr>
<td>Reactive Government</td>
<td>Failed to maintain Ramsey Policy</td>
<td>N/A</td>
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<td>(Decide both (\Theta) and (T) before 2nd Stage)</td>
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<tr>
<td>Non Benevolent Government</td>
<td>N/A</td>
<td>Successful to maintain Ramsey Policy in certain range</td>
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<tr>
<td>(Decide (\Theta) before 1st Stage</td>
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\(^{(1)}\) Full paper is available upon request
Today’s Agenda

1. Introduction
2. Literature Review
3. Model Formulation
4. Economic Analysis & Simulation Results
5. Conclusion
6. Q&A
Introduction

- **Current Situation**
  Extraordinary funding gap to maintain existing transportation network and construct new infrastructures

- **Corresponding Policy**
  <The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA)>

- **Now is a good timing**

- **Problem to solve**
  Investigate public-private administration and collaboration in capacity investment and pricing decisions in highway systems
Literature Review

- Traces back to De Palma and Leruth (1989)
- Most research focuses on pricing decisions
  
  Verhoef et al., 1996; De Palma and Lindsey, 2000; Van Dender, 2005
- Trend to investigate capacity investment in 2000s
  
  Verhoef and Rouwendal, 2004; De Borger and Van Dender, 2006; De Borger et al., 2007; Ubbels and Verhoef, 2008; Borger et al., 2009
- Shift from Engineering solution to Economic Policy
- User differentiation emerges as more important
  
  Levinson, 2000; Small and Yan, 2001; Verhoef and Small, 2004
Policy interests start to expand beyond local area

Pisarsky, 1987; Nijkamp and Rienstra, 1995; Madrick, 1996; Levinson, 2000; Vickerman, 2009

Network structure does matter

Parallel: De Palma and Leruth, 1989; Verhoef et al., 1996; Liu and McDonald, 1998; De Palma and Lindsey, 2000; De Borger et al., 2005; Van Dender, 2005; De Borger and Van Dender, 2006

Serial: Levinson, 2000; De Borger et al., 2007; Ubbels and Verhoef, 2008

Mixed: Verhoef and Small, 2004; Verhoef and Rouwendal, 2004; De Borger et al., 2008

Variations includes different modes competition or sustainability evaluation

De Palma et al., 2007; Pels and Verhoef, 2007; De Borger et al., 2008
Model Formulation

- Public-Private Partnership: Government vs. Concessionaire

- Two-Stage Game (Backward Induction):
  - Capacity Investment + Pricing Strategies
  - Two-Ownership Regime in Pricing Stage:
    - Compare the pricing decisions under the administration of government and private party
  - Mixed-Ownership Regime in Capacity Stage:
    - Investigate private party’s best capacity investment for local traffic zone, and government’s best capacity decision for through traffic zone to adjust overall social welfare
Model Formulation

- Serial Network
- Inverse Demand Functions: Through and Local ($P_X(X)$ and $P_Y(Y)$)
- Decision Variables: Tolls ($\theta_X$ and $\theta_Y$); Capacities ($Z_T$ and $Z_M$)
- User Cost Function: $K(\beta, \rho)$, $\rho=V/Z$, $\beta$ is user specific VOT
- Generalized Cost Functions: $g^X(X)$ and $g^Y(Y)$
- User Equilibrium: $P_X(X)=g^X(X)$, $P_Y(Y)=g^Y(Y)$
- Reduced Demand Functions: $X^r(\theta_X, \theta_Y, Z_T, Z_M)$, $Y^r(\theta_X, \theta_Y, Z_T, Z_M)$
User Equilibrium

- **UE for Through and Local Traffic:**

  \[ P^X(X) = g^X(X) = K^X(\rho_T) + K^X(\rho_M) + \theta_X \]

  \[ P^Y(Y) = g^Y(Y) = K^Y(\rho_M) + \theta_Y \]

- **Reduced Demand Functions:**

  \[ X = X^r(\theta_X, \theta_Y, Z_T, Z_M) \]

  \[ Y = Y^r(\theta_X, \theta_Y, Z_T, Z_M) \]

<table>
<thead>
<tr>
<th>Through Traffic</th>
<th>Local Traffic</th>
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<tr>
<td>( \frac{\partial X^r}{\partial \theta_X} = \frac{1}{\Delta_2} &lt; 0 )</td>
<td>( \frac{\partial Y^r}{\partial \theta_X} = \frac{\partial z}{\partial X} \cdot \frac{\partial X}{\partial \theta_X} &gt; 0 )</td>
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<td>( \frac{\partial Y^r}{\partial \theta_Y} = \frac{\partial z}{\partial X} \cdot \frac{\partial X}{\partial \theta_Y} + \frac{\partial z}{\partial \theta_Y} &lt; 0 )</td>
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<tr>
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Two ownership regimes in pricing stage

1. Social-welfare maximizing under public administration
2. Profit maximizing under private administration
Public Objectives & Optimal Rules

- Objective function for government:

\[
\max_{\theta_X, \theta_Y} S_C = \int_0^Y (P_Y(y)) \, dy - g^Y Y + \theta_X X + \theta_Y Y - C(Z_M)
\]

- Optimal pricing rules by government:

\[
\begin{align*}
\theta_Y &= LMC + X \cdot K^Y \cdot \frac{1}{Z_M} \\
\theta_X &= LMC - X \cdot \frac{\partial Y}{\partial \theta_X} \cdot \frac{\partial Y}{\partial \theta_Y}
\end{align*}
\]

- Insights:

Price for local traffic exceeds the local marginal cost by an extra amount, which is the marginal cost for through traffic by adding one more user, multiplied by the share of through traffic.

\[
\star \quad LMC = Y \cdot K^Y \cdot \frac{1}{Z_M} = K^Y \left( \frac{X + Y}{Z_M} \right) \cdot \frac{Y}{Z_M}
\]

May 24, 2011

Zitao Zhang, Northwestern University  

May 24, 2011
Private Objectives & Optimal Rules

- Objective function for private party:

\[
\max_{\theta_X, \theta_Y} \pi_P = \theta_X X + \theta_Y Y - C(Z_M)
\]

- Optimal pricing rules by private party:

\[
\begin{align*}
\theta_Y &= LMC + X \cdot K_x \frac{X}{Z_M} - Y \cdot \frac{\partial P_Y}{\partial Y} \\
\theta_X &= LMC - X \cdot \frac{\partial Y}{\partial \theta_X} \cdot \frac{\partial z}{\partial \theta_Y}
\end{align*}
\]

- Insights:

There is a mark-up in the price charged for local traffic.
Private party tends to charge local traffic users based on their elasticity. This is the side effect of private administration, as private party tends to have a stronger socially inefficient motive for tolling (profit seeking) than socially efficient motive (congestion internalization).
Tax-Exporting Behavior

Tax-Exporting Behavior (Public & Private)

Mixed-traffic Marginal Cost (MMC):

\[ MMC = K'' \cdot \frac{Y}{Z_M} + K' \cdot \frac{X}{Z_M} \]

Tolls:

\[ \theta_Y = MMC \]
\[ \theta_X = MMC - X \cdot \frac{\partial P_X}{\partial X} + K' \cdot \frac{X}{Z_T} \]

Tax Exporting:

\[ \theta_X - \theta_Y = -X \cdot \frac{\partial P_X}{\partial X} + K' \cdot \frac{X}{Z_T} > 0 \]

Weakened Tax-Exporting Behavior (Private vs. Public)

Differences between tolls:

\[ (\theta_X^P - \theta_Y^P) - (\theta_X^G - \theta_Y^G) = (X^P - X^G) \cdot \left( \frac{K'X}{Z_T} - \frac{\partial P_X}{\partial X} \right) + Y^P \cdot \frac{\partial P_Y}{\partial Y} < 0 \]
Effect of Heterogeneous Users

Different Regime’s toll changes with different $\beta$ ratio

Government Tolls vs. Private Tolls
$\beta$ Ratio changing with Capacity fixed

$\theta_Y$ Amount ($\)$

$\theta_X$ Amount ($\)$

$Z_M=1000, Z_T=1000$

$\beta_Y/\beta_X$

$\theta_Y$-gov, $\theta_Y$-pri

$\theta_X$-gov, $\theta_X$-pri
Effect of Heterogeneous Users

Social Welfare vs. Profit with different β ratio

Social Welfare vs. Private Profit
β Ratio changing with Capacity fixed

Monetary Value
$ * 100000

0 0.5 1 1.5 2 2.5 3 3.5

0.1 0.5 1 1.5 5

Z_M=1000, Z_I=1000

β_Y/β_X

Social Welfare
Private Profit
Effect of Through Capacity

Local Toll ($\theta_Y$) & Demand Change with increasing Through Capacity ($Z_T$)

Simulation Results

Local Traffic Toll and Demand Change under Public and Private Administration with increasing through capacity

- $\theta_Y$-gov
- $\theta_Y$-pri
- Y-gov
- Y-pri
Effect of Through Capacity

Through Toll ($\theta_X$) & Demand Change with increasing Through Capacity ($Z_T$)

Simulation Results

Through Traffic Toll and Demand Change under Public and Private Administration with increasing through capacity

Toll Amount ($) vs. Through Traffic Demand

- $\theta X$-gov
- $\theta X$-pri
- X-gov
- X-pri

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Effect of Local Capacity

Local Toll ($\theta_Y$) & Demand Change with increasing Local Capacity ($Z_M$)

Local Traffic Toll and Demand Change under Public and Private Administration with increasing local capacity

![Graph showing toll and demand change with increasing local capacity](image_url)
Effect of Local Capacity

Through Toll ($\theta_X$) & Demand Change with increasing Local Capacity ($Z_M$)

Simulation Results

Through Traffic Toll and Demand Change under Public and Private Administration with increasing local capacity

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Effect of Through Capacity on Welfare

Social Welfare & Profit Change with increasing Through Capacity ($Z_T$)

Simulation Results

Social Welfare vs. Private Profit
$Z_T$ changing with $Z_M$ fixed

- $eta_2 = 1.5 \beta_1$
- Social Welfare (Blue Line)
- Private Profit (Red Line)
Effect of Local Capacity on Welfare

Social Welfare & Profit Change with increasing Local Capacity ($Z_M$)

Simulation Results

Social Welfare vs. Private Profit

$Z_M$ changing with $Z_T$ fixed

Monetary Value

$\beta_2 = 1.5\beta_1$

$\beta_2 = 1.5\beta_1$

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$\beta_2 = 1.5\beta_1$
Interim Summary

- Users heterogeneity would induce more aggressive public tolling, while reducing the social welfare under public administration.

- Expansion of through capacity has a trivial impact on users benefits as well as tolling decisions.

- Expansion of local capacity leads to more obvious profit seeking or social-welfare enhancing behavior.

Time to wake up!!!
Mixed-ownership in capacity stage

- Two parties together provide capacity for two links

1. Government take initiative to provide through traffic zone’s capacity, considering regional users social welfare, while not including private profit *

2. Private party observe government’s decision and respond accordingly
Private Party’s Problem:

\[
\max_{Z_M} \pi_P = \theta_X X + \theta_Y Y - C(Z_M)
\]

\[
= \theta_X X + \theta_Y Y - (F + kZ_M)
\]

Optimal Local Zone Capacity Rule:

\[
\theta_X \cdot \frac{\partial X}{\partial Z_M} + \theta_Y \cdot \frac{\partial Y}{\partial Z_M} = k
\]

Insights:

The right-hand side is the capacity expansion cost by adding one more unit of capacity, and the left-hand side is the increased toll revenue by induced demand of capacity expansion. One thing important to notice is that the toll adjustment terms (i.e. \(\partial \theta_X / \partial Z_M\) and \(\partial \theta_Y / \partial Z_M\)) do not emerge, as they have already been determined optimally by the private party.
Government’s Problem:

\[
\max_{Z_T} S_G = \int_0^X (P^X(x)) \, dx - g^X X + \int_0^Y (P^Y(y)) \, dy - g^Y Y - C(Z_T)
\]

Optimal Through Zone Capacity Rule:

\[
k = X \cdot \left[ \frac{K'^X X}{Z_T^2} + \frac{K'^X (X+Y)}{Z_M^2} \cdot \frac{\partial Z_M}{\partial Z_T} - \frac{K'^X (Z_T + Z_M)}{Z_T Z_M} \cdot \frac{dX}{dZ_T} - \frac{K'^X}{Z_M} \cdot \frac{dY}{dZ_T} - \frac{d\theta_X}{dZ_T} \right] \\
+ Y \cdot \left[ \frac{K'^Y (X+Y)}{Z_M^2} \cdot \frac{\partial Z_M}{\partial Z_T} - \frac{K'^Y}{Z_M} \cdot \left( \frac{dX}{dZ_T} + \frac{dY}{dZ_T} \right) - \frac{d\theta_Y}{dZ_T} \right]
\]

Insights:

The left-handside is the cost required for adding one more unit of capacity, and the right-handside is the induced total travel cost reduction from through traffic and local traffic users.

Note that there is no direct toll change since we don’t incorporate private profit into consideration

- Numerical Difficulty: an equation of 5th order or more…
Capacity Simulation Results

How government’s capacity decision of $Z_T$ influence $Z_M$?

The Change of Optimal $Z_M$ with $Z_T$ Increasing

Optimal point
Support without terms:

$$\max_{Z_T} S_{GP} = \int_0^X (P^X(x)) \, dx - g^X X + \int_0^Y (P^Y(y)) \, dy - g^Y Y - C(Z_T) + \phi \cdot \pi_P$$

Optimal Through Zone Capacity Rule:

$$\left(1 + \phi \cdot \frac{\partial Z_M}{\partial Z_T}\right) k = X \cdot K^X \left[ \frac{(X + Y)}{Z_M^2} \cdot \frac{\partial Z_M}{\partial Z_T} + \frac{X}{Z_T^2} - \frac{(Z_T + Z_M)}{Z_T Z_M} \cdot \frac{dX}{dZ_T} \frac{1}{Z_M} \cdot \frac{dY}{dZ_T} \right]$$

$$+ Y \cdot K^Y \left[ \frac{(X + Y)}{Z_M^2} \cdot \frac{\partial Z_M}{\partial Z_T} - \frac{1}{Z_M} \cdot \left( \frac{dX}{dZ_T} \frac{dY}{dZ_T} \right) \right]$$

$$- (1 - \phi) \left[ X \cdot \frac{d\theta_X}{dZ_T} + Y \cdot \frac{d\theta_Y}{dZ_T} \right] + \phi \left( \theta_X \cdot \frac{dX}{dZ_T} + \theta_Y \cdot \frac{dY}{dZ_T} \right)$$

Welfare Transfer:

$$\Delta \pi_P = \theta_X \cdot \frac{dX}{dZ_T} + \theta_Y \cdot \frac{dY}{dZ_T} + X \cdot \frac{d\theta_X}{dZ_T} + Y \cdot \frac{d\theta_Y}{dZ_T} - k \cdot \frac{\partial Z_M}{\partial Z_T}$$

$$= !?@ < \# \phi \psi \Xi \Box X Y (messy \ derivation...$$

$$= \theta_X \cdot \frac{\partial X}{\partial Z_T} + \theta_Y \cdot \frac{\partial Y}{\partial Z_T} > 0$$

- Numerical Difficulty: an equation of 5th order or more...
Conditional Collaboration

- Support with terms:

\[
\max_{Z_T} S_{GP} = \int_0^X (P^X(x)) \, dx - g^X X + \int_0^Y (P^Y(y)) \, dy - g^Y Y - \rho \cdot C(Z_T) + \phi \cdot \pi_P
\]

s.t. \((1 - \phi) \cdot \pi_P \geq (1 - \rho) \cdot C(Z_T)\)

- Optimal Through Zone Capacity Rule:

\[
\left(1 + \frac{\partial Z_M}{\partial Z_T}\right)_k = X \cdot K' \left[ \frac{(X + Y)}{Z_M^2} \cdot \frac{\partial Z_M}{\partial Z_T} + \frac{X}{Z_T^2} - \frac{(Z_T + Z_M)}{Z_T Z_M} \cdot \frac{dX}{dZ_T} - \frac{1}{Z_M} \cdot \frac{dY}{dZ_T} \right]
\]

\[
+ Y \cdot K' \left[ \frac{(X + Y)}{Z_M^2} \cdot \frac{\partial Z_M}{\partial Z_T} - \frac{1}{Z_M} \cdot \left( \frac{dX}{dZ_T} + \frac{dY}{dZ_T} \right) \right]
\]

\[
+ \left( \frac{\theta_X}{dZ_T} + \frac{\theta_Y}{dZ_T} \right)
\]

- Cost structure does matter (in brief)
Conclusions

- **Tolling**
  - a) Government charges lower local toll than private party
  - b) Both parties have shown “tax-exporting” behavior
  - c) Diminishing “tax-exporting” effect under private administration

- **User Heterogeneity Effect** *(as local user becomes more significant)*
  - a) Both parties tend to increase tolls on through traffic
  - b) Private party will reduce local toll as government tend to increase that
  - c) Government would reach a similar level of social welfare with private party
Conclusions

- **Capacity Investment**
  - a) Asymmetric capacity outcome
  - b) Inelastic respond to the adjacent capacity change
  - c) Pricing is a more powerful tool to respond to capacity expansion

- **Public-Private Collaboration**
  - a) Welfare transfer: users’ benefits from toll savings due to through traffic zone capacity expansion becomes private party’s additional toll revenue
  - b) Government can control the level of welfare transfer by incorporate partial private profit into consideration
  - c) The best way is to collaborate rather than compete in capacity investment
Any Questions?

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