Intercity Competition and the Urban Transport System

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Motivation

- In the US, funding and other decisions concerning the design and organization of the transportation system have typically been structured from the "top" to the "bottom"
- More recently, and partly due to the federal government's financial struggles, the entire organization of the transportation system has been under scrutiny
  - The United States Highway Trust Fund (HTF) is undergoing severe solvency problems and its future is unclear.
- There is some academic discussion about the role the federal government should play in such decisions
- This paper aims at contributing to this debate.

Motivation

- Some advocate for switching from a central to a decentralized transportation system.
- Glaeser (2012): "defederalization" of the transportation system
  - If states are granted the responsibility of financing their own transportation infrastructure, they would internalize the costs of their decisions and spend less and more efficiently.
- Some research, however, suggests that decentralization leads to higher transportation expenditures.
- Decentralization also creates other opportunities:
  - Design of transportation systems tailored to local needs
  - Development of new and diverse transportation alternatives.

Motivation

- Supporters of a leading role of the federal government:
  - If the transport system is defederalized states would tend to underinvest in their segments of the national highway or rail systems.
  - States would need to use increasingly distortive taxes to fund their transportation networks, and the burden of such measures tend to disproportionately fall on low-income residents.
- This paper focuses on one of the challenges of defederalization: strategic behavior of local transportation authorities.

Objective

- Examine theoretically the implications of shifting from a centralized to a decentralized organization of the transportation system
- Consider different objective functions: cities's surplus, consumption (under various landownership arrangements)
- Framework of analysis:
  - Urban equilibrium model with two employment centers or CBDs.
  - Brueckner and Selod (2004): CBD transport authority chooses from a variety of transportation systems
  - Transportation systems are characterized by time transportation costs (or speed) and money transportation costs.
    $\Rightarrow$ Faster transportation systems (lower commuting time costs) vs. higher money costs.

The Model

- Closed, linear urban area: unit width, represented by the interval $[0, 1]$
- Two employment centers: CBD_0 at 0, CBD_1 at 1; distance from CBD_0 is x, distance from the CBD_1 is $(1 - x)$
- $N = 1$ identical residents, commute to work to CBD_0/CBD_1
  - N_i commuters to CBD_i
  - Income: net labor income $(+)$ share of total land rents
  - Rent earned by the non-urban land is zero
- Two goods: land and composite non-land good z
  - Land: consume fixed amount of land $= 1$
  - Good z: produced at CBD_0 and CBD_1 using labor; CRS technology
    - Output in CBD_i: $y_i L_i$, $y_i > 0, L_i$ effective amount of labor
    - A consumer would earn the wage y_i in CBD_i in the absence of commuting

The Model: Transport Cost

- Total Transport Cost (TTC):

$$TTC = TTC_0 + TTC_1$$

  where $TTC_i = C_i + T_i + F_i$
- Money Cost (C_i): depends on t_i, cost per mile of travel
- Time Cost (T_i): depends on time spent commuting
  - ϕ_i: inverse of transport system's speed
  - A commute of x miles to CBD_i implies a time cost of $\phi_i x$
  - $y_i(1 - \phi_i x)$: income net of time cost of commuting x miles to CBD_i
- Fixed cost (F_i): fixed cost of setting up a transportation network with speed $1/\phi_i$ and length $\bar{x}$

$$F_i = k(t_i)\bar{x}$$

- Transport systems characterized by $\{t_i, \phi_i\}$
  - $\phi_i \equiv \phi(t_i)$, with $\phi'(\cdot) < 0$ and $\phi(\cdot)'' > 0$

Optimal Transportation System

Optimal Solution

$$\text{Maximize } \mathcal{S} = \mathcal{S}_0 + \mathcal{S}_1 \text{ w.r.t. } \{t_0, t_1, x^*\}$$

- Total Social Surplus = Total Production $(-)$ TTC

$$\mathcal{S}_i = y_i L_i - TTC_i, i = 1, 2$$

- Effective amount of labor:

$$L_0 = \int_0^{x^*} [1 - \phi(t_0)x]dx \quad L_1 = \int_{x^*}^1 [1 - \phi(t_1)(1 - x)]dx$$

- Total transport costs: $TTC_i = T_i + C_i + F_i$

$$\begin{aligned} TTC_0 &= \int_0^{x^*} y_0\phi(t_0)dx + \int_0^{x^*} t_0 x dx + k(t_0)x^* \\ TTC_1 &= \int_{x^*}^1 y_1\phi(t_1)(1 - x)dx + \int_{x^*}^1 t_1(1 - x)dx + k(t_1)(1 - x^*) \end{aligned}$$

Optimal Transportation System

- Substituting into $\mathcal{S}$ gives

$$\begin{aligned}\mathcal{S} &= x^* \left\{ y_0 - k(t_0) - [y_0\phi(t_0) + t_0]\frac{x^*}{2} \right\} \\ &\quad +(1-x^*)\left\{ y_1 - k(t_1) - [y_1\phi(t_1) + t_1]\frac{(1-x^*)}{2} \right\}\end{aligned}$$

- From FOCs:

$$-\left[y_0\phi'(t_0) + 1\right]\frac{x^{*2}}{2} = k'(t_0)x^*$$

$y_0\phi'(t_0)$: increase in total production at CBD_0 per mile traveled due to an increase in t_0
$x^{*2}/2$: total miles traveled

and

$$x^* = \frac{[y_0 - k(t_0)] - [y_1 - k(t_1)] + [y_1\phi(t_1) + t_1]}{[y_0\phi(t_0) + t_0] + [y_1\phi(t_1) + t_1]}$$

Equilibrium Analysis: Land Market Equilibrium

- Budget constraints:
  - Commutes to CBD_0

$$z_0 + r(x) \quad = \quad a + y_0 - \tau_0 - [y_0\phi(t_0) + t_0]x$$

  - Commutes to CBD_1

$$z_1 + r(1-x) \quad = \quad a + y_1 - \tau_1 - [y_1\phi(t_1) + t_1](1-x)$$

$r(x)$: land rent per unit of land at distance x from CBD_0
a: share of land rents
τ_i: share of fixed costs paid by residents commuting to i

Equilibrium Analysis: Land Market Equilibrium

Definition

A land market equilibrium in a closed, linear urban area is a vector $\{z, x^*\}$ such that:

- All individuals (working at CBD_0 and CBD_1) obtain the same utility at all locations x: $z_0 = z_1 = z$
- $r(x^*) = r(1 - x^*) = 0$
- Commuters to CBD_0 and CBD_1:

$$\int_0^{x^*} dx = N_0, \quad \int_{x^*}^1 dx = N_1$$

- Equilibrium land rent at x: $\max\{r(x), r(1-x), 0\}$

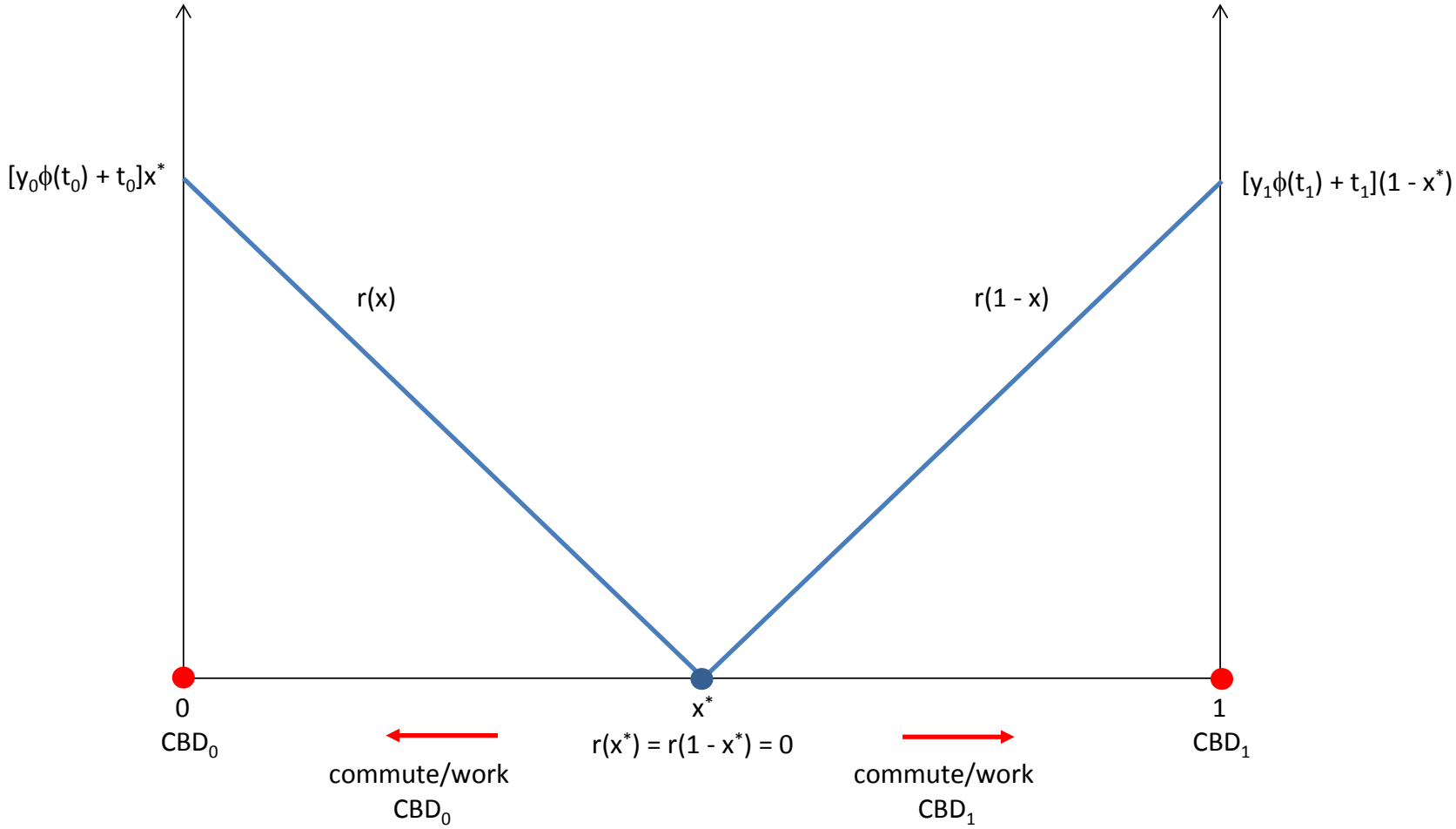
Equilibrium Analysis: Land Market Equilibrium
Derivation of Bid-Rent Curves

- x^* determines who work at/commutes to each employment center:

$$x^* = \frac{(y_0 - \tau_0) - (y_1 - \tau_1) + [y_1\phi(t_1) + t_1]}{[y_0\phi(t_0) + t_0] + [y_1\phi(t_1) + t_1]}$$

- Bid-rent curves:
  - CBD_0: $r(x) = [y_0\phi(t_0) + t_0](x^* - x)$
  - CBD_1: $r(1 - x) = [y_1\phi(t_1) + t_1](x - x^*)$

Equilibrium Analysis



Equilibrium Analysis: Land Market Equilibrium
Equilibrium Consumption

- Substituting $r(x)$ and $r(1-x)$ into the budget constraints gives the equilibrium consumption level

$$\begin{aligned} z &= a + \tilde{z} \\ &= a + y_0 - \tau_0 - [y_0\phi(t_0) + t_0]x^* \\ &= a + y_1 - \tau_1 - [y_1\phi(t_1) + t_1](1 - x^*) \end{aligned}$$

$\Rightarrow$ Consumption is equal to disposable income at the edge of each city

Equilibrium Analysis: Land Market Equilibrium
Aggregate Land Rent

- Aggregate land rent R is given by

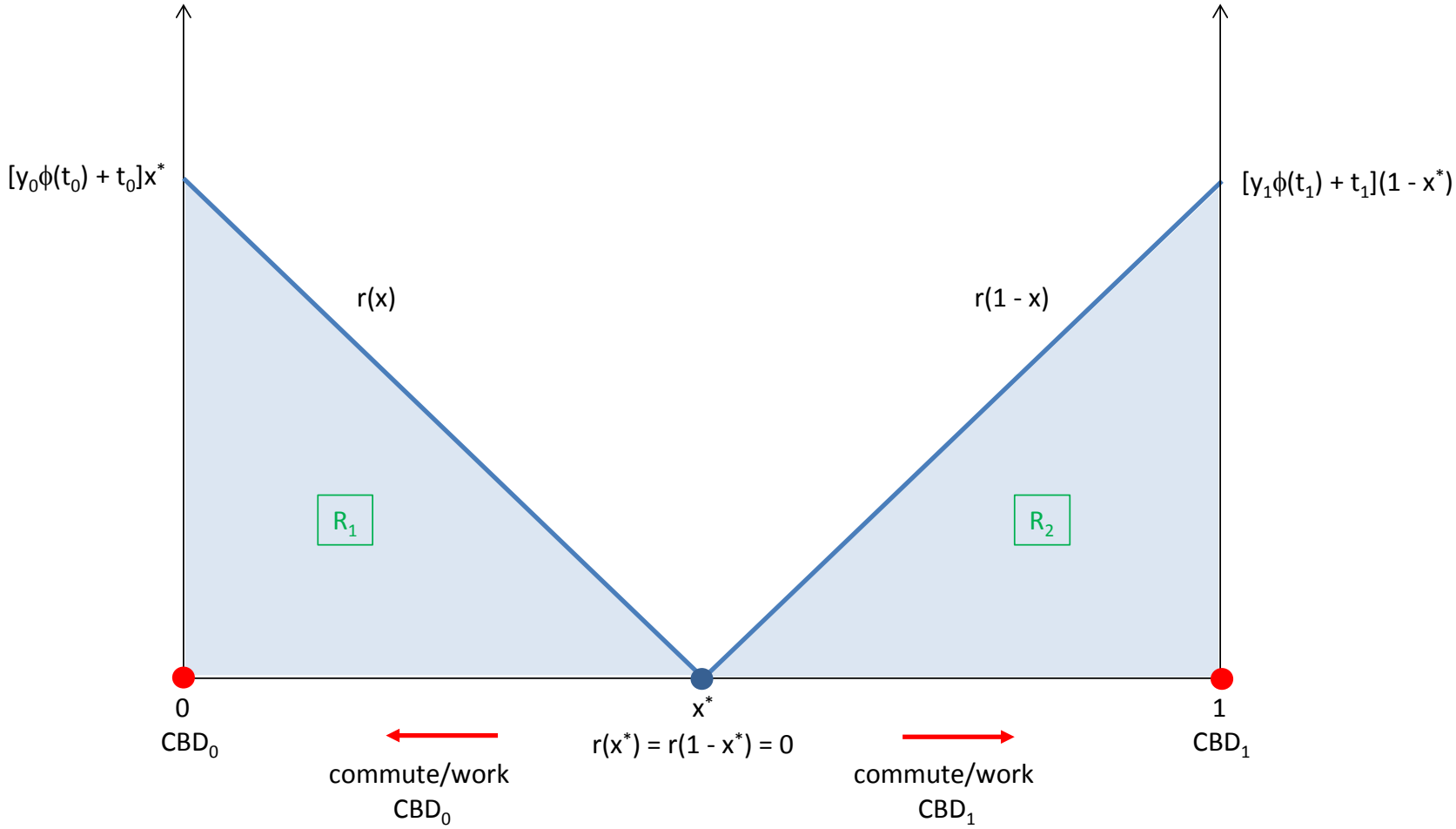
$$\begin{aligned} R &= R_0 + R_1 \\ &= \int_0^{x^*} r(x)dx + \int_{x^*}^1 r(1-x)dx \\ &= [y_0\phi(t_0) + t_0]\frac{x^{*2}}{2} + [y_1\phi(t_1) + t_1]\frac{(1-x^*)^2}{2} \end{aligned}$$

- R is also the average land rent, ALR $(N = 1)$
- Each resident receives a share $0 \leq \theta \leq 1$ of ALR

$$a \equiv \theta R$$

- If $\theta = 0$, landowners live outside the cities (absentee-landowner case), and if $\theta = 1$, land is entirely owned by local residents.

Equilibrium Analysis



Choice of the Transport System: Timing

1. Transport authority (central, or local) chooses t_i that maximizes the corresponding objective function anticipating the land market equilibrium
   - In the decentralized case, city i chooses t_i taking the transport system chosen by j as given
2. After observing the previous choices, individuals decide their residential locations and commuting destination (CBD_0 or CBD_1)

- Assume for the moment that fixed costs F_i are equally financed by commuters to i: $\tau_i = k(t_i)$

Choice of the Transport System: Total Surplus Centralized Solution

Total Surplus, Centralized

Maximize $S = S_1 + S_2$ w.r.t. $\{t_0, t_1\}$, anticipating x^*, where city i's total surplus S_i is

$$S_i = y_i L_i - \tau_i - T_i - C_i$$

Proposition

Suppose that residents of city i equally share the fixed cost associated with the transportation system in city i, F_i. Then, a central transportation authority that maximizes total surplus chooses the optimal transportation systems t_0^{CS} and t_1^{CS}.

Choice of the Transport System: Total Surplus Decentralized Solution

Total Surplus, Decentralized

Maximize S_i w.r.t. to t_i taking t_j as given, anticipating x^*

- In the decentralized case:

$$-\left[y_0\phi'(t_0)+1\right]\frac{x^{*2}}{2}=\gamma k'(t_0)x^*$$

where $0<\gamma<1$

- In the centralized case:

$$-\left[y_0\phi'(t_0)+1\right]\frac{x^{*2}}{2}=k'(t_0)x^*$$

Choice of the Transport System: Total Surplus
Comparing the Results

Proposition

Suppose that transportation authorities (central or local) maximize total surplus. Let t_i^{CS} denote the value of t_i chosen by a central transport authority (i.e., when it maximizes $S = S_1 + S_2$), and t_i^{DS} the equilibrium values when cities act in a decentralized way (i.e., when each city maximizes its own surplus S_i) for $i = 0, 1$. Then, $t_i^{DS} > t_i^{CS}$ and $\phi(t_i^{DS}) < \phi(t_i^{CS})$.

- In other words, when cities behave strategically, they tend to overinvest in the transportation system: they will choose more expensive, and faster transport systems.

Choice of the Transport System: Total Surplus
Comparing the Results

- Consider the external effect generated by city 0 on city 1
- Evaluated at the equilibrium, $\partial x^* / \partial t_0 > 0$

$$\frac{\partial S_1}{\partial t_0} = -\{y_1 - k(t_1) - [y_1 \phi(t_1) + t_1](1 - x^*)\} \frac{\partial x^*}{\partial t_0}$$

- The expression between brackets is the disposable income or consumption at the border of city 1, which is positive
  $\Rightarrow (\partial S_1 / \partial t_0) < 0$

Choice of the Transport System: Total Surplus
Discussion of Results

- Note that

$$\begin{aligned} S &= S_0 + S_1, \\ &= x^*[y_0 - k(t_0)] - R_0 + (1 - x^*)[y_1 - k(t_1)] - R_1, \end{aligned}$$

where the land rent R_i is the sum of the time and money transportation costs, i.e, $R_i = T_i + C_i$ (Arnott and Stiglitz (1979))

Choice of the Transport System: Total Consumption Centralized Solution

Total Consumption, Centralized Case

Maximize $W = x^* z_0 + (1 - x^*) z_1$ w.r.t. $\{t_0, t_1\}$, anticipating x^*

$$\Rightarrow \frac{\partial W}{\partial t_i} = \frac{\partial \tilde{z}_i}{\partial t_i} + \theta \frac{\partial R}{\partial t_i} = 0, \quad i = 0, 1.$$

- Note that $\partial \tilde{z}_i / \partial t_i = 0$ if

$$[y_0 \phi'(t_0) + 1] x^* + k'(t_0) = 0,$$
$$[y_1 \phi'(t_1) + 1](1 - x^*) + k'(t_1) = 0.$$

  $\Rightarrow$ Equilibrium conditions for t_0 and t_1 when $\theta = 0$.
- When these conditions are met, $\partial R / \partial t_i < 0$ and $\partial W / \partial t_i < 0$.
  $\Rightarrow$ If $0 < \theta \leq 1$, the values of t_i that maximize z are lower than those that maximize $\tilde{z}$.

Choice of the Transport System: Total Consumption Centralized Solution

Proposition

The values of t_0 and t_1 that maximize $z = a + \tilde{z}$ are higher when $\theta = 0$ (absentee landlord case), than when $0 < \theta \leq 1$ (residents receive at least part of the ALR).

Choice of the Transport System: Total Consumption Centralized Solution

- It is straightforward to show that when $\theta = 1$, $W = \mathcal{S}$

Proposition

When the central transport authority maximizes total consumption and $0 \leq \theta < 1$, it chooses higher values of t_0 and t_1 than the optimal values. The centralized solutions are optimal when $\theta = 1$.

Choice of the Transport System: Total Consumption Decentralized Solution

Total Consumption, Decentralized Case

Maximize $W_0 = x^* z_0$ w.r.t. t_0 (taking t_1 as given) and maximize $W_1 = (1 - x^*) z_1$ w.r.t. t_0 (taking t_0 as given), anticipating x^*

- From FOCs:

$$\begin{aligned}
\frac{\partial W_0}{\partial t_0} &= (\tilde{z}_0 + \theta R)\frac{\partial x^*}{\partial t_0} + x^* \left(\frac{\partial \tilde{z}_0}{\partial t_0} + \theta \frac{\partial R}{\partial t_0} \right) = 0, \\
\frac{\partial W_1}{\partial t_1} &= -(\tilde{z}_1 + \theta R)\frac{\partial x^*}{\partial t_1} + (1 - x^*) \left(\frac{\partial \tilde{z}_1}{\partial t_1} + \theta \frac{\partial R}{\partial t_1} \right) = 0.
\end{aligned}$$

Choice of the Transport System: Total Consumption Decentralized Solution

- Suppose that $\theta = 0$, so $z = \tilde{z}$. The equilibrium in this case is achieved when

$$[y_0\phi'(t_0) + 1]x^* + k'(t_0) = 0,$$
$$[y_1\phi'(t_1) + 1](1 - x^*) + k'(t_1) = 0.$$

- Same as in the centralized case
  - City size $[(x^* \text{ or } (1 - x^*)]$ and $\tilde{z}_i$ are maximized at the same values of t_i
  - When these conditions hold,

$$\partial x^*/\partial t_0 = \partial x^*/\partial t_1 = \partial z_0/\partial t_0 = \partial z_1/\partial t_1 = 0$$

$\Rightarrow$ The strategic competition effect that would arise in the decentralized case vanishes.

Choice of the Transport System: Total Consumption Decentralized Solution

- Suppose that $0 < \theta \leq 1$:

$$\partial x^* / \partial t_i = \partial \tilde{z} / \partial t_i = 0, \partial R / \partial t_i < 0 \Rightarrow \partial W_i / \partial t_i < 0$$

Proposition

When the transport system is decided in a decentralized way, and city transport authorities maximize total consumption within the city, the equilibrium values of t_0 and t_1 are higher when $\theta = 0$ than when $0 < \theta \leq 1$.

Choice of the Transport System: Total Consumption
Comparing the Results

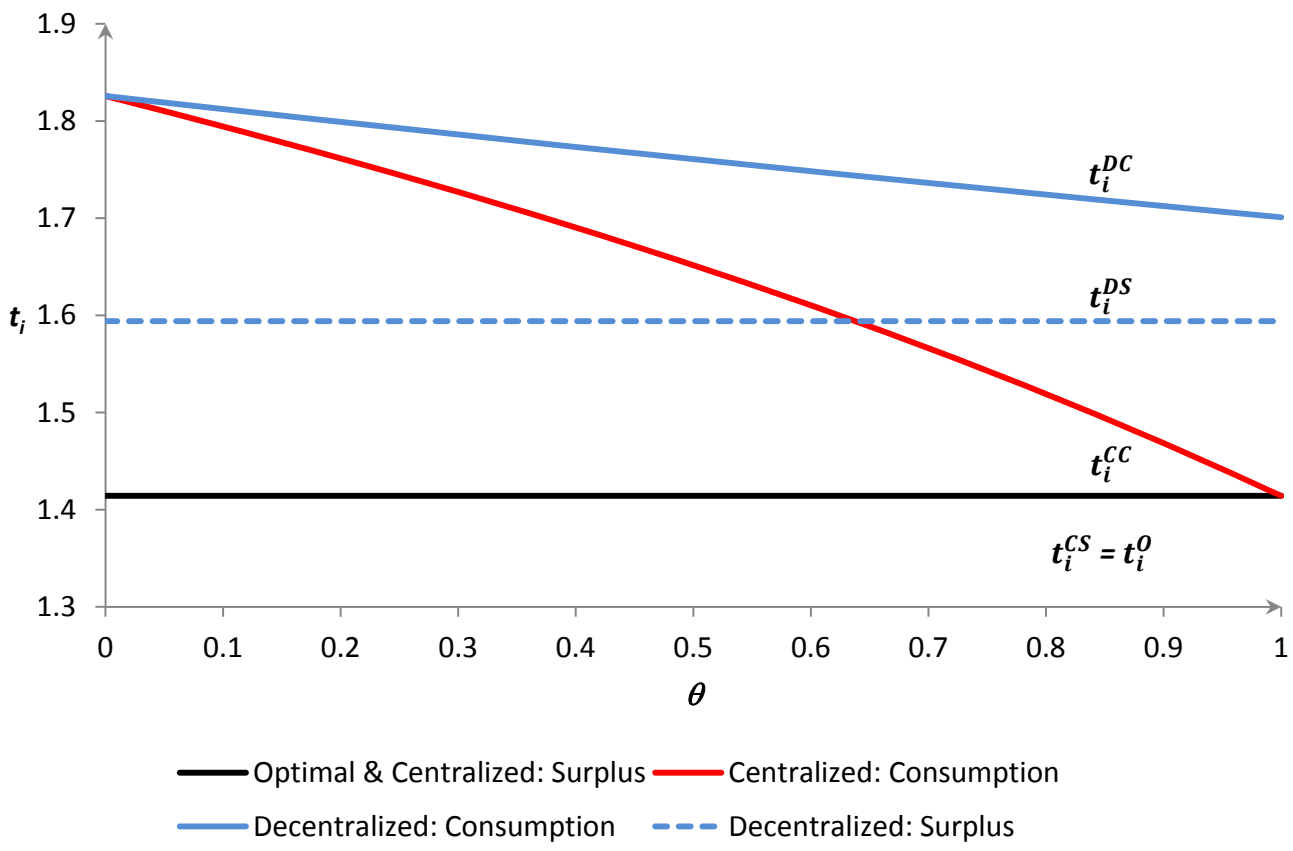
Proposition

Suppose that the transport authorities both in the centralized and decentralized cases choose the values of t_i that maximize consumption (aggregate consumption or total consumption within the city, respectively). Specifically, $\{t_0^{CC}, t_1^{CC}\}$ is the solution in the centralized case and $\{t_0^{DC}, t_1^{DC}\}$ is the solution in the decentralized case. Then,

(i) *If $\theta = 0$, then $t_i^{DC} = t_i^{CC}, i = 0, 1$.*

(ii) *If $0 < \theta \leq 1$, $t_i^{DC} > t_i^{CC}, i = 0, 1$.*

Choice of the Transport System: Total Consumption
Comparing the Results



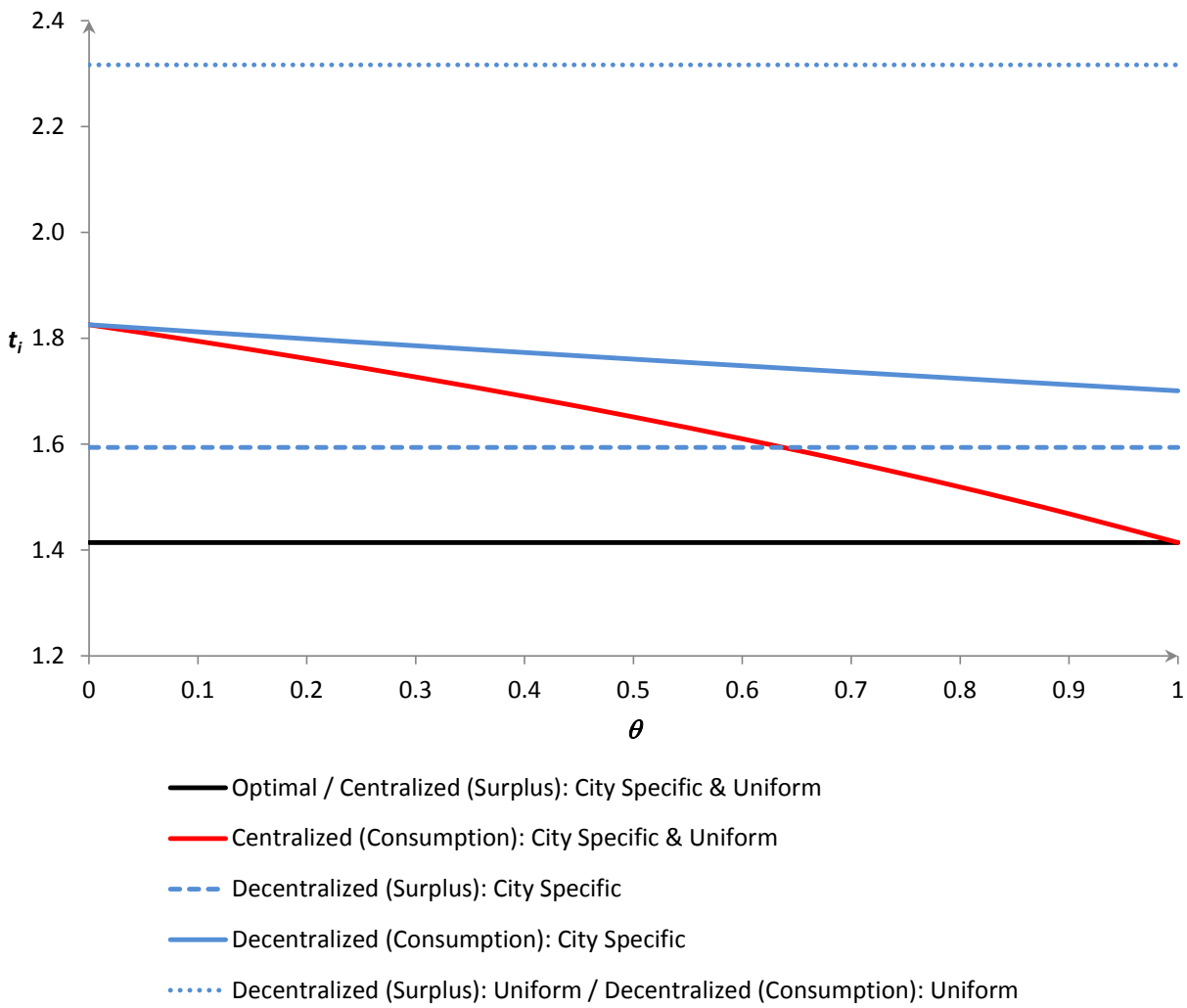
Choice of the Transport System: Alternative Financing Mechanisms

- Suppose $\tau_0 = \tau_1 = \tau = k(t_0)x^* + k(t_1)(1 - x^*)$
- x^* no longer depends on $k(t_0)$ and $k(t_1)$:

$$x^* = \frac{(y_0 - y_1) + [y_1\phi(t_1) + t_1]}{[y_0\phi(t_0) + t_0) + (y_1\phi(t_1) + t_1]}$$

- Total surplus:
  - Centralized: In general, solutions are no longer optimal
    - A uniform tax is optimal only when cities are identical
  - Decentralized: Cities choose larger t_i's
- Consumption:
  - Centralized: t_i is inefficiently high; t_i declines as θ increases
    - If cities are identical, t_i is the same as the one with city specific taxes
  - Decentralized: When cities are identical, if the tax is uniform, then t_i is independent of θ
    - In this case t_i is the same as the one that maximizes the city's surplus

Choice of the Transport System: Alternative Financing Mechanisms



Conclusions

1. Study the implications of shifting from a centralized to a decentralized arrangement of the transportation system
2. When local transportation authorities make their decisions in a decentralized way, they would not internalize the impact of their choices on other jurisdictions
3. Establish conditions under which the decentralized case would lead to overinvestment in transportation relative to the centralized
   - When transport authorities choose transportation systems that maximize total surplus, the outcome in the decentralized case is larger than the outcome in the centralized case
   - When the objective is to maximize total consumption and residents receive part of the aggregate land rents
   - In the absentee landlord case, the centralized and decentralized solutions coincide
4. The distortion gets larger in the decentralized case when a uniform tax is used to finance the transport system

Extensions

1. Congestion
2. Subsidize money transportation cost
3. Other alternative financing mechanisms
4. System of cities
    - Transport interconnectivity within the city and across cities