Impact of Transport Supply and Demand Management Strategies on Land Value

Hong K. Lo
Xiaosu Ma

Department of Civil and Environmental Engineering
Hong Kong University of Science & Technology

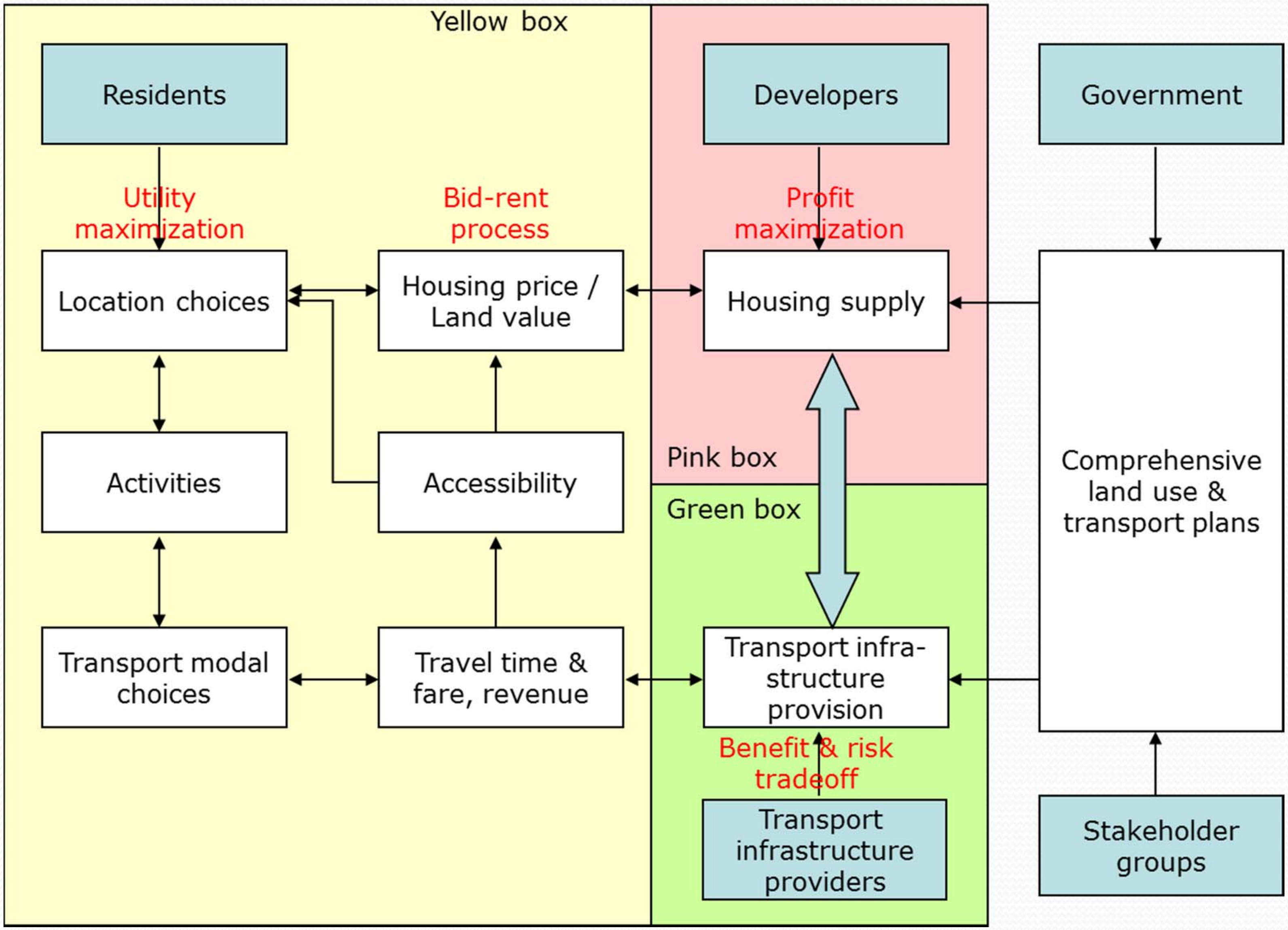
Profitability of Operators

Return rates	MTR (rail): Average after opening of the Airport Railway (1998 – 2006)	KMB (bus): Average over last 5 years (2002-2006)
Operating margin before tax	6.0%	14%
Operating return on net fixed asset	0.7%	14%
Total return (including property profit) on net fixed asset	5.1%	N/A

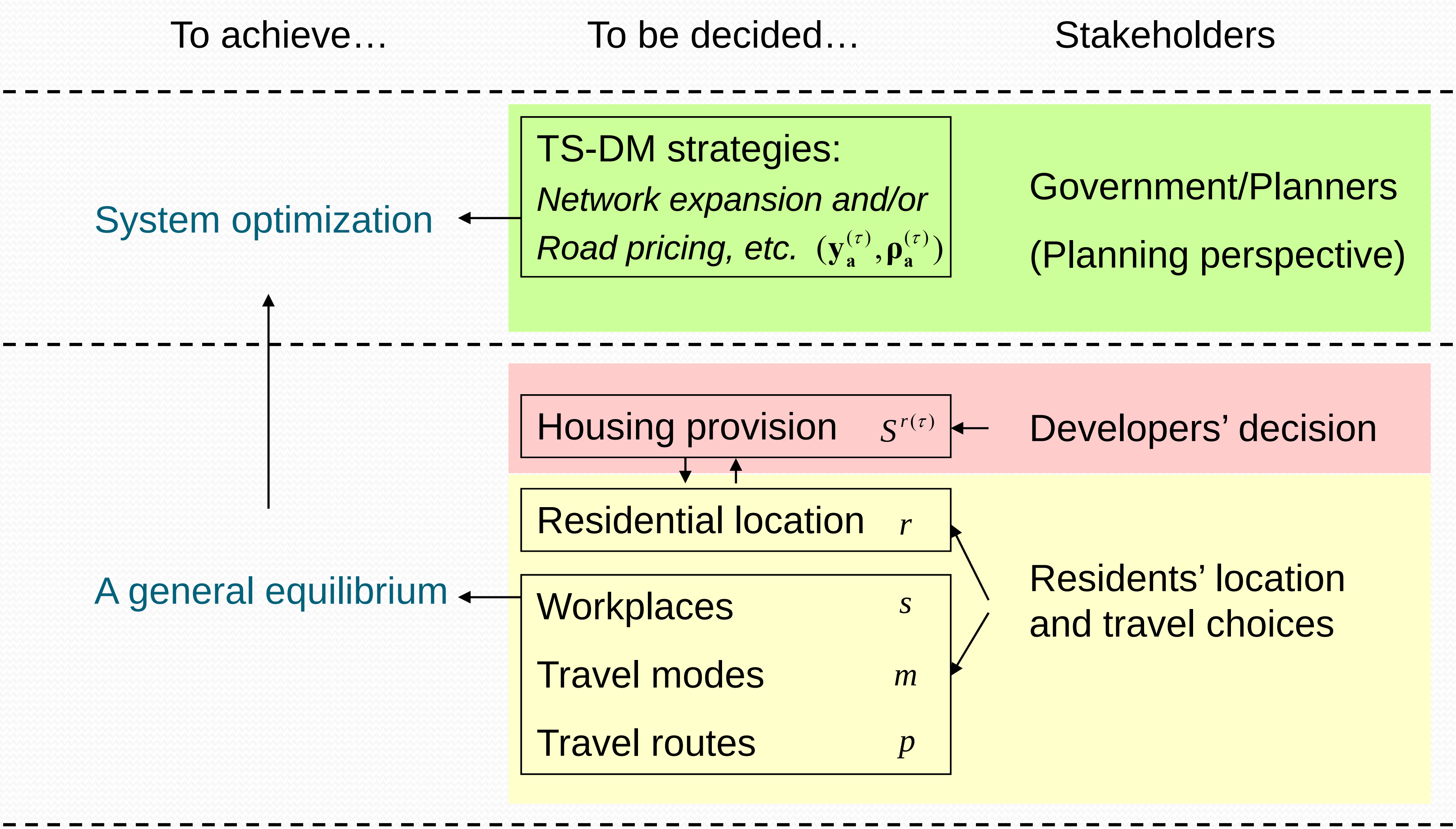
Objectives

- To analyze public policies, e.g. railway development strategies, cross-subsidization between housing market and transportation infrastructure projects, public housing provision
- To investigate the distribution of costs and returns among different stakeholders.
- To develop an analytical framework for an integrated land use and transport system.
- To study the impact of transport management strategies on residential location choices and the resultant land value.

An integrated land use and transport system…



…modeled by an analytical framework



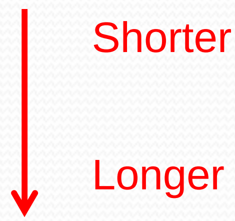
A general equilibrium formulation

- Resident location choice problem
  - Bid-rent at different locations
  - Transportation cost/accessibility
  - Housing supply
  - Utility maximization

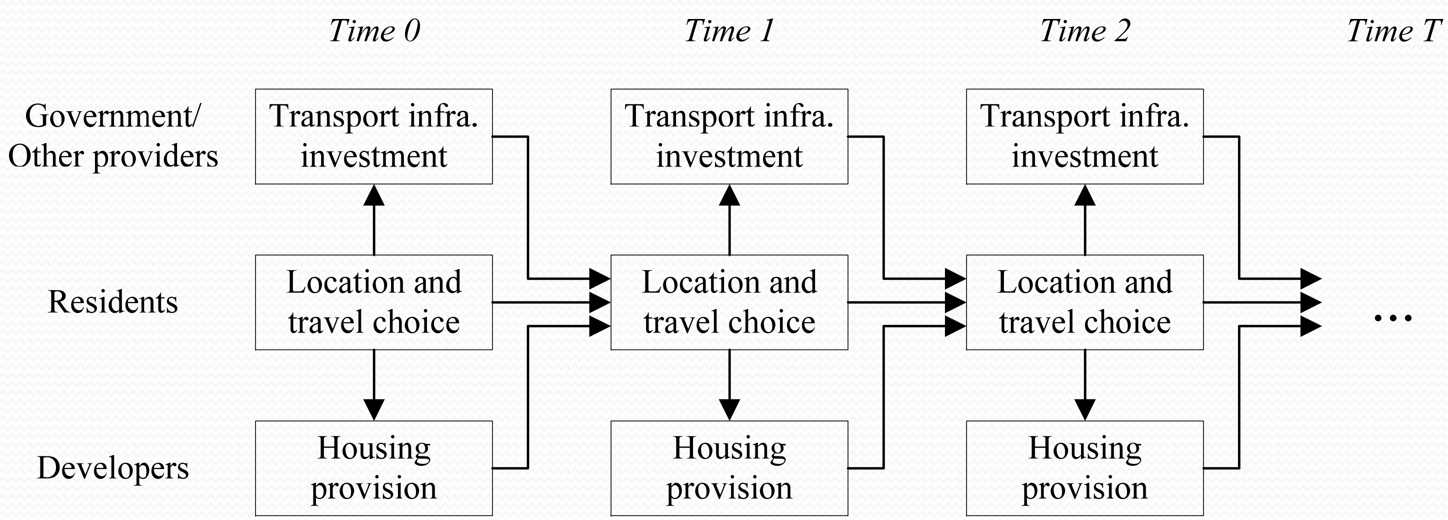
- Developer housing supply problem
  - Bid-rent at different locations
  - Cost of housing supply
  - Profit maximization

General equilibrium formulation over time

- A quasi dynamic structure
  - Different time adaptabilities of sub-systems
    - Residents' travel behavior
    - Residents' location choice
    - Housing investment
    - Transport infrastructure investment

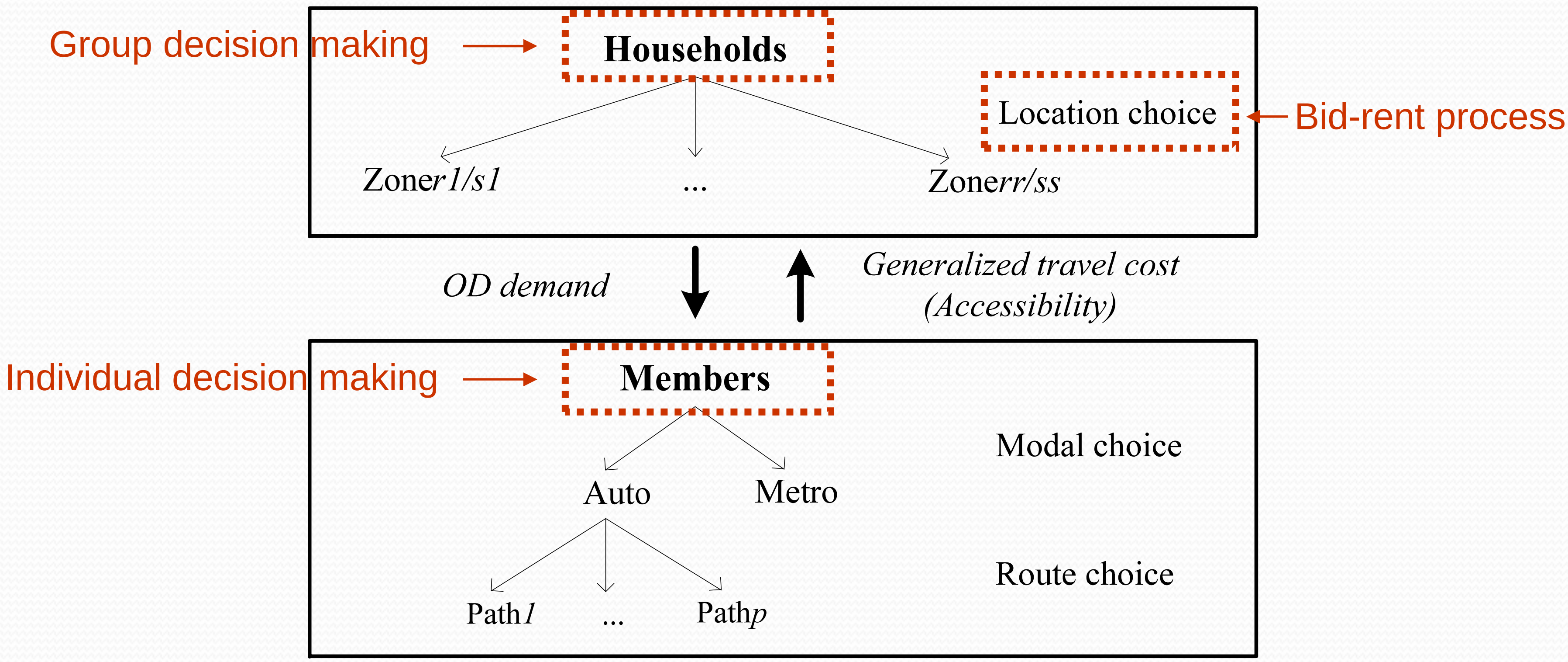


  - Implying that given a time period τ, residents' location and travel choices are made under a fixed land use and transport system



Resident location choice problem

- Bid-rent process for residential location choice
- Household "*with multi-members*"



Residential location choice

- For each residential location, the rent is derived based on residents' willingness-to-pay for that location

$$WP^{k/r(\tau)} = I^{k(\tau)} - f(U^{k/r(\tau)}) + \sum_i \alpha_i^k \cdot X_i^{r(\tau)} + l^{rk(\tau)} - \mu^{rk(\tau)} + wp$$

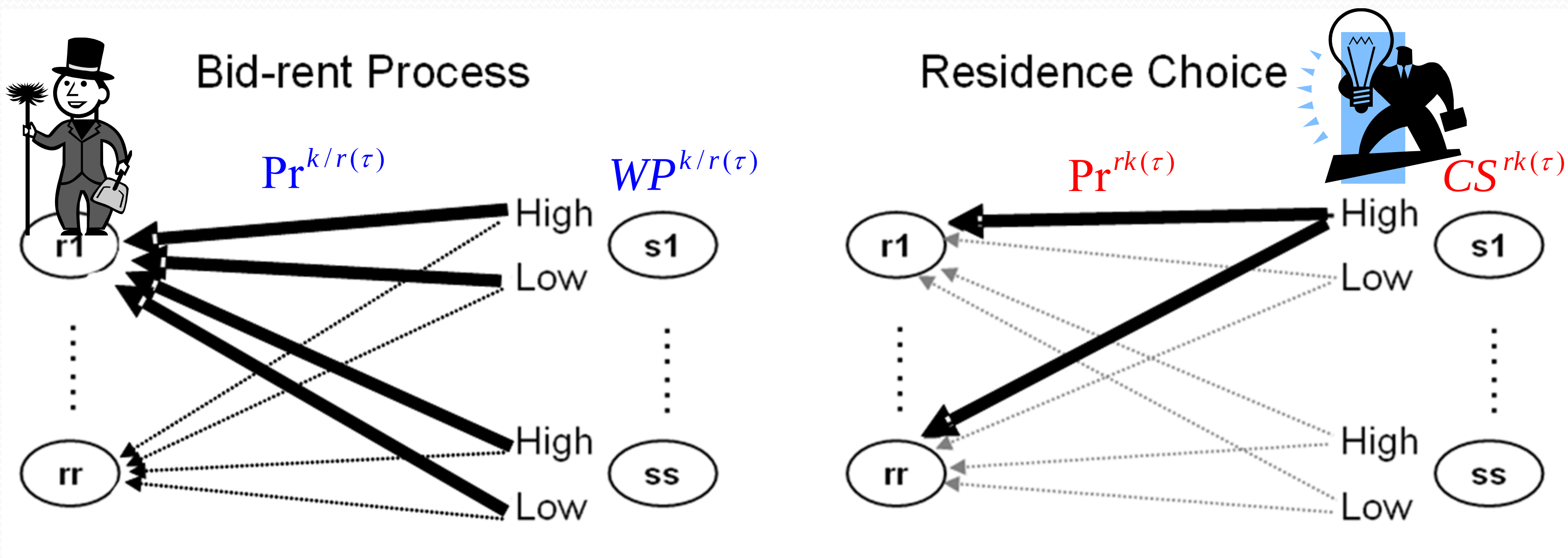
$$WP^{k/r(\tau)} = b^{k(\tau)} + \sum_i \alpha_i^k \cdot X_i^{r(\tau)} + l^{rk(\tau)} - \mu^{rk(\tau)}$$

where,

$b^{k(\tau)}$	—	*Utility index by setting* $b^{k(\tau)} = I^{k(\tau)} - f(U^{k/r(\tau)}) + wp$
$I^{k(\tau)}$	—	*Household income*
$X_i^{r(\tau)}$	—	*Intrinsic housing attributes, e.g. lot size, building age, etc.*
$l^{rk(\tau)}$	—	*Location externalities influenced by location and travel choices*
$\mu^{rk(\tau)}$	—	*Generalized travel cost / Accessibility*

Residential location choice

- The two choice processes is mathematically proven to produce identical residential location choices; hence they are consistent



From the perspective of landowners

From the perspective of residents

Residential location choice

- According to the bid-rent process, the location *r* to be occupied by residents of income group *k* is expressed the following probability

$$\Pr^{k/r(\tau)} = \frac{\exp\left(\beta_r^{(\tau)} \cdot WP^{k/r(\tau)}\right)}{\sum_{k'} \exp\left(\beta_r^{(\tau)} \cdot WP^{k/r'(\tau)}\right)}$$

$$O^{rk(\tau)} = S^{r(\tau)} \cdot \Pr^{k/r(\tau)}$$

From the perspective of landowners:

Different income groups are potential choices for the landowner to rent to

Groups offering higher WP would have a higher probability to be chosen by the landowner

The resultant housing rent/price in location *r* is expressed by the log-sum term, adjusted by the housing supply at that location:

$$\varphi^{r(\tau)} = \frac{1}{\beta_r^{(\tau)}} \ln\left(\sum_{k' \in K} \exp\left(\beta_r^{(\tau)} \cdot WP^{k'/r(\tau)}\right)\right) - \frac{1}{\beta_r^{(\tau)}} \cdot \ln(S^{r(\tau)})$$

Residential location choice

- From the perspective of residents, they will choose a residence that maximize their utility, expressed as a consumer surplus term defined as:

$$CS^{rk(\tau)} = WP^{k/r(\tau)} - \varphi^{r(\tau)}$$

(Household's) consumer surplus

$$\Pr^{rk(\tau)} = \frac{\exp\left(\beta_r^{(\tau)} \cdot CS^{rk(\tau)}\right)}{\sum_{r'} \exp\left(\beta_r^{(\tau)} \cdot CS^{r'k(\tau)}\right)}$$

$$O^{rk(\tau)} = H^{k(\tau)} \cdot \Pr^{rk(\tau)}$$

From the perspective of residents:

Different locations are choices for resident to choose from

The location that offers a higher consumer surplus for income group k would have a probability of being chosen by them

Residential location choice

- OD demand
  - In the planning process, with some aggregation assumptions, classifying households into *k* income groups
  - Assuming there are exogenous job choice models, i.e.
    - the proportions to each work destination *s* for each income group *k* are fixed, i.e.

$$\sum_{s} \Pr^{sk(\tau)} = 1$$

    - the average number of workers per household in each income group *k* are also given, i.e.

$$n^{k(\tau)}$$

  - Then the resultant OD demand is obtained by

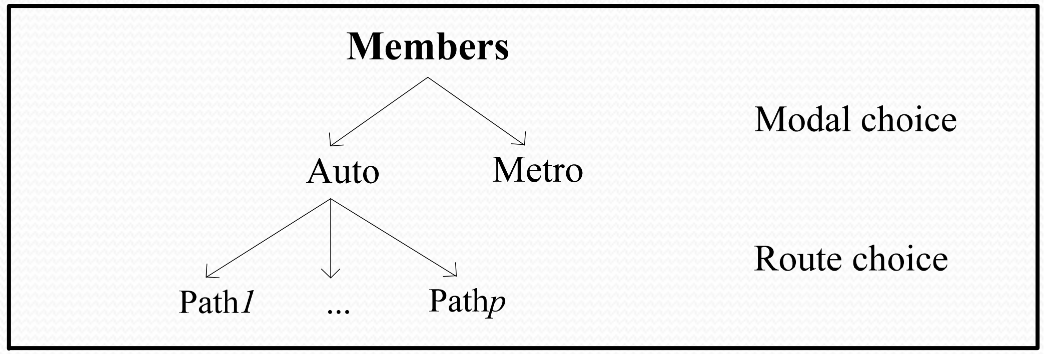
$$q^{rsk(\tau)} = O^{rk(\tau)} \cdot \Pr^{sk(\tau)} \cdot n^{k(\tau)}$$

Travel choice

- Household member's travel choice

$$V_m^{rsk(\tau)} = \beta_m^{k(\tau)} \cdot c_m^{rsk(\tau)} + \gamma_m^{k(\tau)} \rightarrow$$

$$V_{p|m}^{rsk(\tau)} = -c_{p|m}^{rsk(\tau)} \rightarrow$$



$$\Pr_{p,m}^{rsk(\tau)} = \frac{\exp(\beta_m^{(\tau)} \cdot V_m^{rsk(\tau)})}{\sum_{m' \in M^{rs}} \exp(\beta_m^{(\tau)} \cdot V_{m'}^{rsk(\tau)})} \cdot \frac{\exp(\beta_p^{(\tau)} \cdot V_{p|m}^{rsk(\tau)})}{\sum_{p' \in P_m^{rs}} \exp(\beta_p^{(\tau)} \cdot V_{p'|m}^{rsk(\tau)})}$$

- Then the resultant path flow for each transport mode *m* is

$$f_{p,m}^{rsk(\tau)} = q^{rsk(\tau)} \cdot \Pr_{p,m}^{rsk(\tau)}$$

Travel cost

- Link with household's residential location choice

$$\mu^{rsk(n)} = \frac{1}{\beta_m^{(\tau)}} \cdot \ln \sum_{m' \in M^{rs}} \exp(\beta_m^{(\tau)} \cdot V_{m'}^{rsk(n)})$$

Individual's perceived travel cost

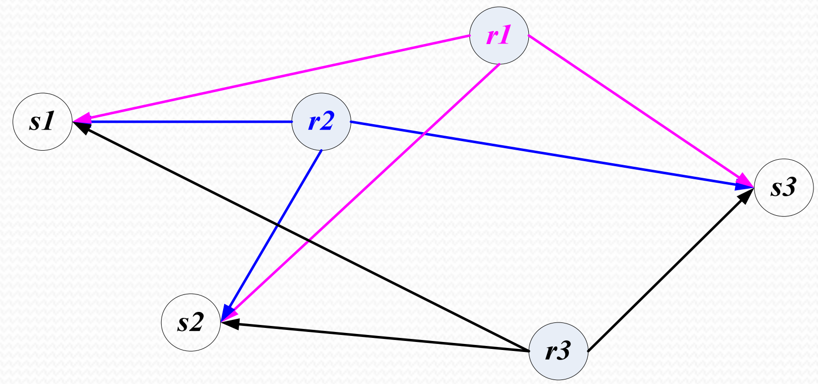
$$\mu^{rk(\tau)} = f(\mu^{rsk(n)} \mid n = 1, \ldots, N)$$

Household's perceived accessibility
(Group decision mechanisms)

Household group decision

- Group decision mechanisms to measure locational accessibility
  - (Zhang and Timmermans, 2004, 2005; Zhang *et al*., 2009)
  - Combine the travel costs incurred to different members

$$\mu^{rk} = f(\mu^{rsk(n)} \mid n = 1,\ldots,N)$$



Alternative specifications:

$$\mu^{rk} = \mu^{rsk(1)} + \mu^{rsk(2)} + \ldots + \mu^{rsk(N)}$$ —— *Members' total travel cost*

$$\mu^{rk} = \sum_n (w^{k(n)} \cdot \mu^{rsk(n)})$$ —— *Overall travel cost considering members' relative influences*

where $$w^{k(n)} = \exp\left(\sum_j \chi_j A_j^{k(n)}\right) / \sum_n \exp\left(\sum_j \chi_j A_j^{k(n)}\right)$$

$$\mu^{rk} = \min(\mu^{rsk(n)} \mid n = 1,\ldots,N)$$ —— *To represent the preference of the memb with the lowest travel cost*

Developer housing supply choice

- Developers' decision on housing provision $S^{r(\tau)}$
  - Under the principle of profit maximization

$$\Pr^{r(\tau)} = \frac{\exp(\lambda^{(\tau-n_2)} \cdot \pi^{r(\tau-n_2)})}{\sum_{r' \in R} \exp(\lambda^{(\tau-n_2)} \cdot \pi^{r'(\tau-n_2)})}, \ \forall \tau \geq 0, n_2 \geq 1$$

$$\pi^{r(\tau-n_2)} = \varphi^{r(\tau-n_2)} - b_H^{r(\tau-n_2)}$$

  - Following a quasi dynamic structure

$$S^{r(\tau)} = \begin{cases} S^{r(0)}, \ 0 \leq \tau < n_2 \\ S^{(\tau)} \cdot \Pr^{r(\tau)}, \ \tau \geq n_2 \end{cases}$$

General equilibrium formulation over time

- The problem is formulated as an equivalent Nonlinear Complementarity Problem (NCP)
  - i.e. to find $\mathbf{Z}^* \geq 0$ such that $\mathbf{F}(\mathbf{Z}^*) \geq \mathbf{0}$ and $\mathbf{Z}^{*\mathrm{T}} \cdot \mathbf{F}(\mathbf{Z}^*) = \mathbf{0}$
  - where,

$$\mathbf{Z} = \begin{pmatrix} f_{p,m}^{rsk(\tau)}, \forall r, s, m, p, k, \tau \\ S^{r(\tau)}, \forall r, \tau \geq n_2 \\ b^{k(\tau)}, \forall k, \tau \end{pmatrix}$$

$$\mathbf{F}(\mathbf{Z}) = \begin{pmatrix} f_{p,m}^{rsk(\tau)} - q^{rsk(\tau)} \cdot \mathrm{Pr}_{p,m}^{rsk(\tau)}, \forall r, s, m, p, k, \tau \\ S^{r(\tau)} - S^{(\tau)} \cdot \mathrm{Pr}^{r(\tau)}, \forall r, \tau \geq n_2 \\ \sum_r S^{r(\tau)} \cdot \mathrm{Pr}^{k/r(\tau)} - H^{k(\tau)}, \forall k, \tau \end{pmatrix}$$

General equilibrium formulation over time

- Nonlinear complementarity conditions

$$
\begin{cases}
f_{p,m}^{rsk(\tau)}(f_{p,m}^{rsk(\tau)} - q^{rsk(\tau)} \cdot \Pr_{p,m}^{rsk(\tau)}) = 0, \quad \forall r, s, m, p, k, \tau \\
f_{p,m}^{rsk(\tau)} - q^{rsk(\tau)} \cdot \Pr_{p,m}^{rsk(\tau)} \geq 0, \quad \forall r, s, m, p, k, \tau \\
S^{r(\tau)}(S^{r(\tau)} - S^{(\tau)} \cdot \Pr^{r(\tau)}) = 0, \forall r, \tau \geq n_2 \\
S^{r(\tau)} - S^{(\tau)} \cdot \Pr^{r(\tau)} \geq 0, \forall r, \tau \geq n_2 \\
b^{k(\tau)}(\sum_r S^{r(\tau)} \cdot \Pr^{k/r(\tau)} - H^{k(\tau)}) = 0, \quad \forall k, \tau \\
\sum_r S^{r(\tau)} \cdot \Pr^{k/r(\tau)} - H^{k(\tau)} \geq 0, \quad \forall k, \tau \\
f_{p,m}^{rsk(\tau)} \geq 0, \forall r, s, m, p, k, \tau \\
S^{r(\tau)} \geq 0, \quad \forall r, \tau \geq n_2 \\
b^{k(\tau)} \geq 0, \forall k, \tau
\end{cases}
$$

General equilibrium formulation over time

- Solved by reformulating as a smooth and unconstrained optimization problem by minimizing the gap function to zero

$$\min G(\mathbf{Z}) = \sum_{\tau} \sum_{rsmkp} \vartheta\left(f_{p,m}^{rsk(\tau)},\ f_{p,m}^{rsk(\tau)} - q^{rsk(\tau)} \cdot \Pr_{p,m}^{rsk(\tau)} \right) + \sum_{\tau} \sum_{r} \vartheta\left(S^{r(\tau)},\ S^{r(\tau)} - S^{(\tau)} \cdot \Pr^{r(\tau)} \right) + \sum_{\tau} \sum_{k} \vartheta\left(b^{k(\tau)},\ \sum_{r} S^{r(\tau)} \cdot \Pr^{k/r(\tau)} - H^{k(\tau)} \right)$$

$$\vartheta(c,d) = \frac{1}{2}\phi^{2}(c,d)$$

$$\phi(c,d) = \sqrt{c^{2}+d^{2}} - (c+d)$$

Fischer function

Convex equilibrium formulation over time

- The existence and uniqueness of the equilibrium solutions
  - Proved by formulating as two equivalent convex optimization problems:
  - Residential choice problem

$$\min_{b^{k(\tau)},\varphi^{r(\tau)},x_a^{(\tau)}} Z_1 = \sum_a x_a^{(\tau)} \cdot t_a^{(\tau)} - \sum_a \int_0^{x_a^{(\tau)}} t_a^{(\tau)}(\omega)d\omega - \sum_k H^{k(\tau)} \cdot b^{k(\tau)}$$
$$+\sum_r S^{r(\tau)} \cdot \varphi^{r(\tau)} + \frac{1}{\beta^{(\tau)}} \cdot \sum_{k,r} \exp\left(\beta^{(\tau)} \cdot (WP^{k/r(\tau)} - \varphi^{r(\tau)})\right)$$

  - Housing supply problem

$$\min_{S^{r(\tau)}} Z_2 = \frac{1}{\lambda^{(\tau-n_2)}} \sum_r (S^{r(\tau)} \cdot \ln S^{r(\tau)} - S^{r(\tau)}) - \sum_r S^{r(\tau)} \cdot \pi^{r(\tau-n_2)}$$

$$s.t. \quad S^{r(\tau)} = S^{r(0)}, \ \forall 0 \le \tau < n_2$$
$$S^{r(\tau)} \ge 0, \ \forall \tau \ge n_2$$

Convex equilibrium formulation over time

- First order conditions with respect to $b^{k(\tau)}$:

$$b^{k(\tau)} \frac{\partial Z_1}{\partial b^{k(\tau)}} = b^{k(\tau)} \left[-H^{k(\tau)} + \sum_{r'} \exp\left(\beta^{(\tau)} \cdot (WP^{k/r'(\tau)} - \varphi^{r'(\tau)}) \right) \right] = 0$$

$$H^{k(\tau)} = \sum_{r'} \exp\left(\beta^{(\tau)} \cdot (WP^{k/r'(\tau)} - \varphi^{r'(\tau)}) \right)$$

$$H^{k(\tau)} = \sum_{r'} O^{r'k(\tau)}$$

$$\Pr^{rk(\tau)} = \frac{O^{rk(\tau)}}{H^{k(\tau)}} = \frac{\exp\left(\beta^{(\tau)} \cdot (WP^{k/r(\tau)} - \varphi^{r(\tau)}) \right)}{\sum_{r'} \exp\left(\beta^{(\tau)} \cdot (WP^{k/r'(\tau)} - \varphi^{r'(\tau)}) \right)}$$

Equivalent to the residential choice probability

Convex equilibrium formulation over time

- First order conditions with respect to rent:

$$\frac{\partial Z_1}{\partial \varphi^{r(\tau)}} = S^{r(\tau)} - \sum_k \exp\left(\beta^{(\tau)} \cdot (WP^{k/r(\tau)} - \varphi^{r(\tau)})\right) = 0$$

$$S^{r(\tau)} = \sum_k O^{rk(\tau)}$$

$$\Pr^{k/r(\tau)} = \frac{O^{rk(\tau)}}{S^{r(\tau)}} = \frac{\exp\left(\beta^{(\tau)} \cdot \left(WP^{k/r(\tau)} - \varphi^{r(\tau)}\right)\right)}{\sum_{k'} \exp\left(\beta^{(\tau)} \cdot \left(WP^{k'/r(\tau)} - \varphi^{r(\tau)}\right)\right)} = \frac{\exp\left(\beta^{(\tau)} \cdot WP^{k/r(\tau)}\right)}{\sum_{k'} \exp\left(\beta^{(\tau)} \cdot WP^{k'/r(\tau)}\right)}$$

Equivalent to the bid-rent occupancy probability

- The housing rent can be obtained by making it the subject of the condition

$$\varphi^{r(\tau)} = \frac{1}{\beta^{(\tau)}} \ln\left(\sum_{k'} \exp\left(\beta^{(\tau)} \cdot WP^{k'/r(\tau)}\right)\right) - \frac{1}{\beta^{(\tau)}} \cdot \ln(S^{r(\tau)})$$

Equivalent to the bid-rent

Convex equilibrium formulation over time

- First order conditions with respect to link flow:

$$\frac{\partial Z_1}{\partial x_a^{(\tau)}} = \left(x_a^{(\tau)} - \sum_k \sum_r \exp\left(\beta^{(\tau)} \cdot (WP^{k/r(\tau)} - \varphi^{r(\tau)}) \right) \cdot \Pr_{p,m}^{rsk(\tau)} \cdot \delta_{a,p|m}^{rs(\tau)} \right) \cdot \frac{\partial t_a^{(\tau)}}{\partial x_a^{(\tau)}} = 0$$

$$\left(x_a^{(\tau)} - \sum_{sk} \sum_r q^{rsk(\tau)} \cdot \Pr_{p,m}^{rsk(\tau)} \cdot \delta_{a,p|m}^{rs(\tau)} \right) \cdot \frac{\partial t_a^{(\tau)}}{\partial x_a^{(\tau)}} = 0$$

Equivalent to SUE traffic assignment

$$q^{rsk(\tau)} = O^{rk(\tau)} \cdot \Pr^{sk(\tau)} \cdot n^{k(\tau)}$$

Convex equilibrium formulation over time

- First order conditions with respect to housing supply:

$$\frac{\partial Z_2}{\partial S^{r(\tau)}} = \frac{1}{\lambda^{(\tau-n_2)}} \cdot \ln S^{r(\tau)} - \pi^{r(\tau-n_2)} = 0$$

$$S^{r(\tau)} = \begin{cases} S^{r(0)}, \forall 0 \le \tau < n_2 \\ \exp(\lambda^{(\tau-n_2)} \cdot \pi^{r(\tau-n_2)}), \forall \tau \ge n_2 \end{cases}$$

$$\Pr^{r(\tau)} = \frac{S^{r(\tau)}}{S^{(\tau)}} = \frac{\exp(\lambda^{(\tau-n_2)} \cdot \pi^{r(\tau-n_2)})}{\sum_r \exp(\lambda^{(\tau-n_2)} \cdot \pi^{r(\tau-n_2)})}$$

Equivalent to the housing supply probability

Convex equilibrium formulation over time

- Solution uniqueness conditions

$$\begin{cases}
\dfrac{\partial^2 Z_1}{\partial b^{k_1(\tau)} \cdot \partial b^{k_1(\tau)}} = \beta^{(\tau)} \cdot \sum_r \exp\left(\beta^{(\tau)} \cdot (WP^{k_1/r(\tau)} - \varphi^{r(\tau)})\right) = \beta^{(\tau)} \cdot H^{k_1(\tau)} > 0 \\
\dfrac{\partial^2 Z_1}{\partial b^{k_1(\tau)} \cdot \partial b^{k_2(\tau)}} = 0, \forall k_1 \neq k_2 \\
\dfrac{\partial^2 Z_1}{\partial \varphi^{r_1(\tau)} \cdot \partial \varphi^{r_1(\tau)}} = \beta^{(\tau)} \cdot \sum_k \exp\left(\beta^{(\tau)} \cdot (WP^{k/r_1(\tau)} - \varphi^{r_1(\tau)})\right) = \beta^{(\tau)} \cdot S^{r_1(\tau)} > 0 \\
\dfrac{\partial^2 Z_1}{\partial \varphi^{r_1(\tau)} \cdot \partial \varphi^{r_2(\tau)}} = 0, \forall r_1 \neq r_2 \\
\dfrac{\partial^2 Z_2}{\partial S^{r_1(\tau)} \cdot \partial S^{r_1(\tau)}} = \dfrac{1}{\lambda^{(\tau - n_2)} \cdot S^{r_1(\tau)}} > 0 \\
\dfrac{\partial^2 Z_2}{\partial S^{r_1(\tau)} \cdot \partial S^{r_2(\tau)}} = 0, \forall r_1 \neq r_2
\end{cases}$$

The uniqueness condition of equivalent formulation of SUE w.r.t. link flow (Sheffi, 1985)

General equilibrium formulation over time

- For each time period τ, both residential location choice and housing supply form a general equilibrium
- Assuming that the total housing demand equals to the total supply

$$S^{(\tau)} = \sum_{k \in K} H^{k(\tau)}, \forall \tau$$

- The decision variables are:
  - Household's utility index $b^{k(\tau)}$
  - Individual's travel decision (*path flow*), which encapsulate automatically the residential location choice and transport modal choices $f_p^{rsmk(\tau)}$
  - Housing provision in location *r* in the next time period $S^{r(\tau)}$

Benefit distribution among stakeholders

- The impact of transport supply and demand management on the benefit of
  - heterogeneous income groups of residents
  - housing supplier
- General conditions
  - Single time period
  - One OD pair
  - Fixed housing supply

Benefit distribution among stakeholders

- Proposition 1 – supply management
  - Under conditions
    - (H_0): One OD pair r and s, households with multiple income groups k
    - (H_1): One travel route p, travel time reduced by $\Delta t<0$ with investment cost B_T
    - (H_2): Homogenous value of time, $vot^k=vot>0$
  - Any travel cost reduction due to transport infrastructure improvement, either in time-based or money-based formulation, will lead to an equivalent increase in land or rental value
  - Consumer surplus (household) $\Rightarrow$
  - Housing supplier surplus $\uparrow$

Benefit distribution among stakeholders

- Proposition 2 – supply management
  - Under conditions
    - (H_0)- (H_1)
    - (H_3): Heterogeneous value of time, $vot^1 < vot^2 < \ldots < vot^k$
    - (H_4): Money-based travel cost formulation
  - Residents with higher incomes/higher values of time benefit more from transport improvement as compared with residents with lower incomes/ lower values of time
  - Consumer surplus (household) Lowest → ↗ ↗ ↑ Highest
  - Housing supplier surplus ↑

Benefit distribution among stakeholders

- Proposition 3 – demand management
  - Under conditions
    - (H_0)- (H_1)
    - (H_3): Heterogeneous value of time, $vot^1 < vot^2 < \ldots < vot^k$
    - (H_5): Time-based travel cost formulation
  - Residents with higher incomes/higher values of time benefit more from demand management, e.g. increasing link toll, as compared with residents with lower incomes/lower values of time
  - Consumer surplus (households') Lowest ➡ ↗ ↗ ⬆ Highest
  - Housing supplier's surplus ⬇

Optimal Transport Supply and Demand Management

System optimization

- Different planning perspectives
  - e.g. Maximize social welfare
- Optimal transport management strategies
  - e.g. Transport Supply and Demand Management, i.e.
  - Highway link expansion $\mathbf{y}_{\mathbf{a}}^{(\tau)}$ and link-based congestion pricing $\boldsymbol{\rho}_{\mathbf{a}}^{(\tau)}$
- Under a time-dependent network following a quasi dynamic structure
- With cost recovery conditions

$$NPV = \sum_{\tau} \upsilon(dr,\tau)\cdot(R_T^{(\tau)} + R_H^{(\tau)}) - \sum_{\tau} \upsilon(dr,\tau)\cdot(B_T^{(\tau)} + B_H^{(\tau)}) - \sum_{\tau} \upsilon(dr,\tau)\cdot(M_T^{(\tau)} + M_H^{(\tau)}) \geq 0$$

Producer surplus

System optimization

- Formulated as a mathematical program with equilibrium constraints (MPEC)

$$\underset{\rho_a^{(\tau)}, y_a^{(\tau)}}{\text{Maximize}} \ \text{SW} = \sum_{\tau} \upsilon(dr,\tau) \cdot \sum_{rs} \sum_{k} q^{rsk(\tau)} \cdot CS^{rsk(\tau)} + NPV$$

$$s.t. \quad G(\mathbf{Z}) = 0$$

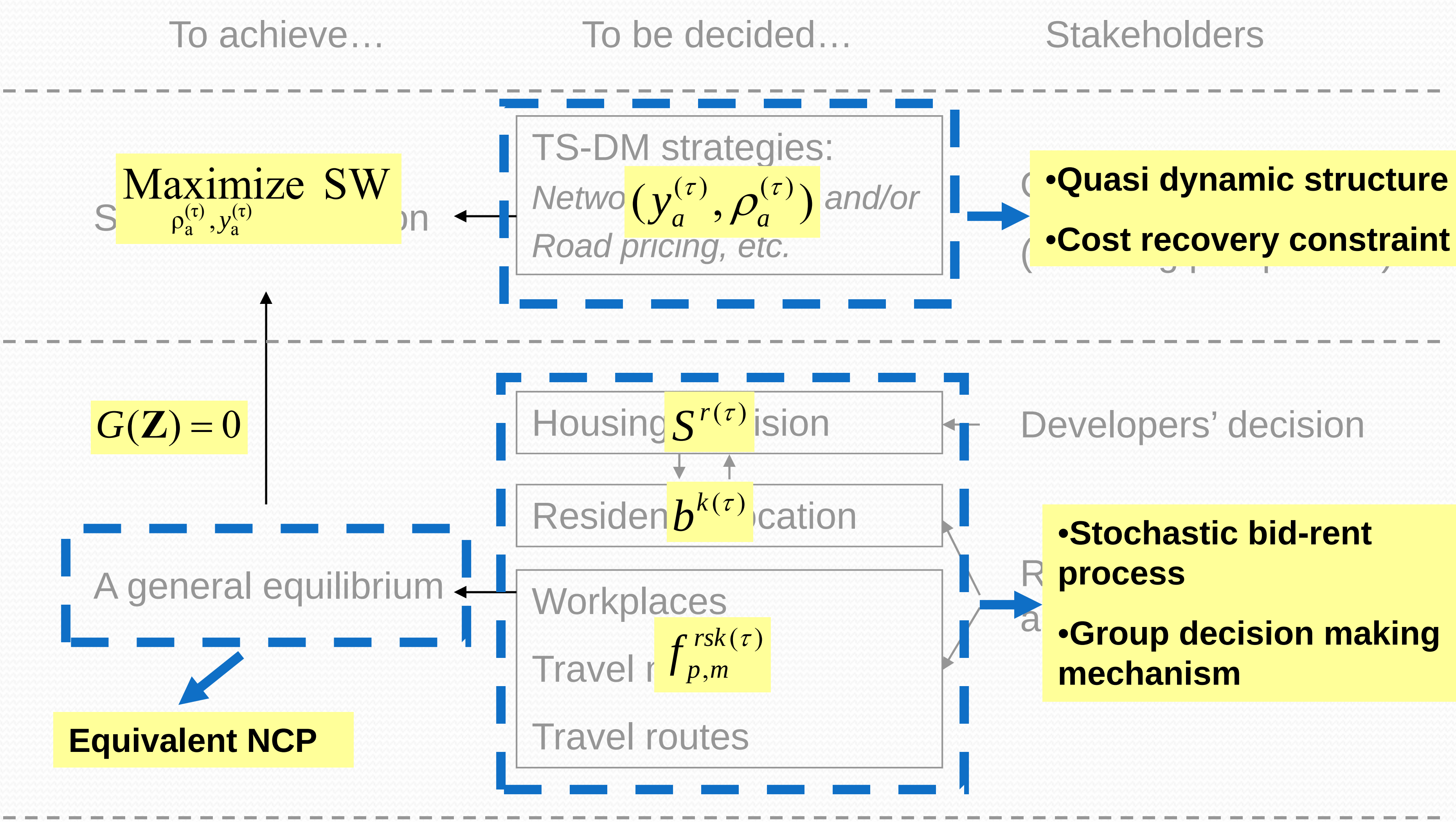
Constraints defined in the general equilibrium formulation

$$NPV \geq 0$$

$$\underline{y_a^{(\tau)}} \leq y_a^{(\tau)} \leq \overline{y_a^{(\tau)}}, \ \forall a, \tau$$

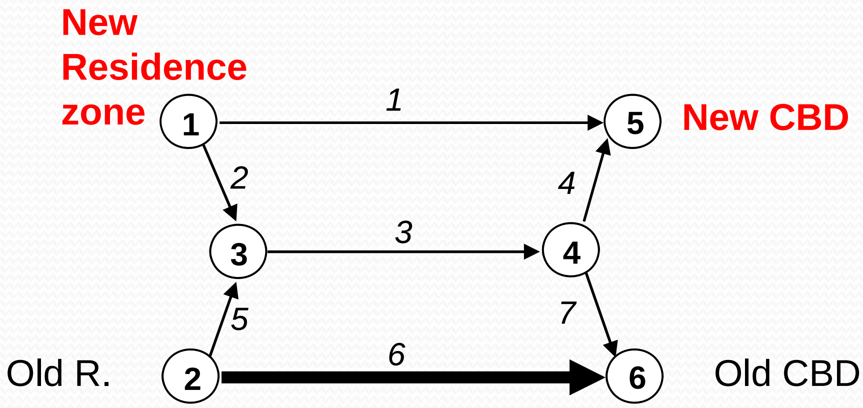
$$\underline{\rho_a^{(\tau)}} \leq \rho_a^{(\tau)} \leq \overline{\rho_a^{(\tau)}}, \ \forall a, \tau$$

To summarize…



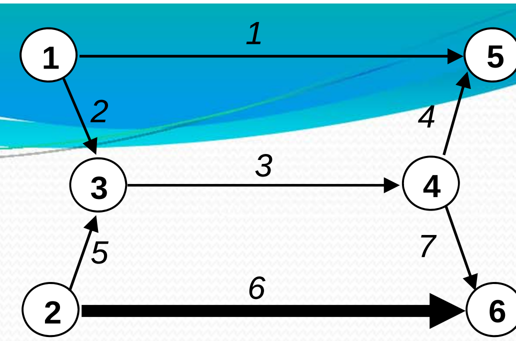
A numerical example

Numerical example

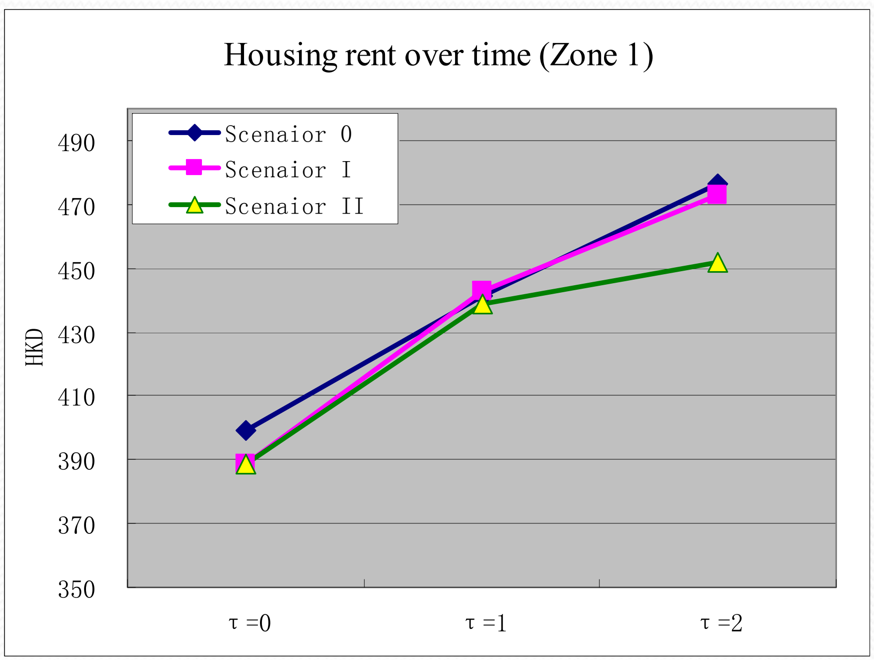


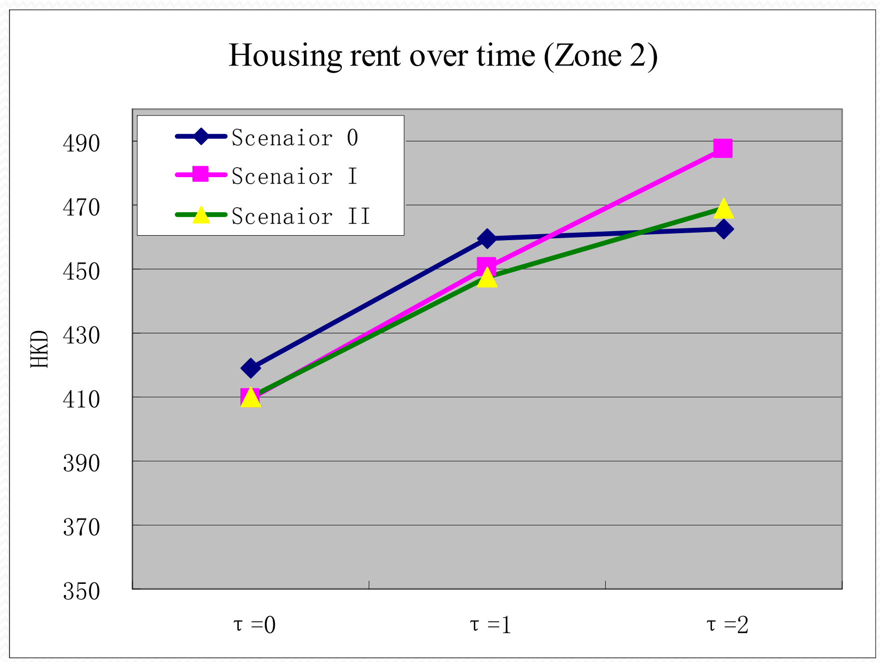
- Network
  - Two residential locations 1,2
  - Two workplaces 5,6
  - Seven links
- Demand
  - Two income groups (high & low)
  - Increasing population for each time interval
  - Workplace choices are exogenously given
- Three time intervals τ=0, 1, 2
- Three scenarios
  - Scenario 0: Do-nothing
  - Scenario I: Welfare maximization with TS-DM
  - Scenario II: Welfare maximization with DM alone

Results



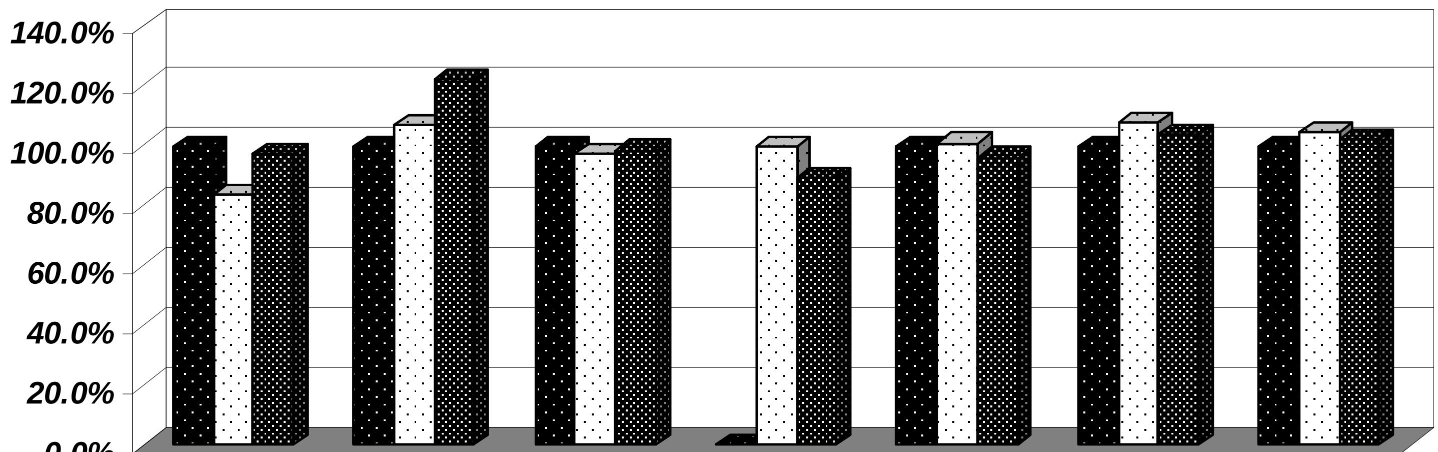
- Housing rents & location choices
  - Transport strategies influence residents' location choices. In the long term, the population distribution is more balanced than "do-nothing"
  - Congestion effects (both transport and location externalities) hurt the rent increase, e.g. Zone 2 in Scenario 0
  - TS-DM leads to higher rent increases than DM scheme alone





Results

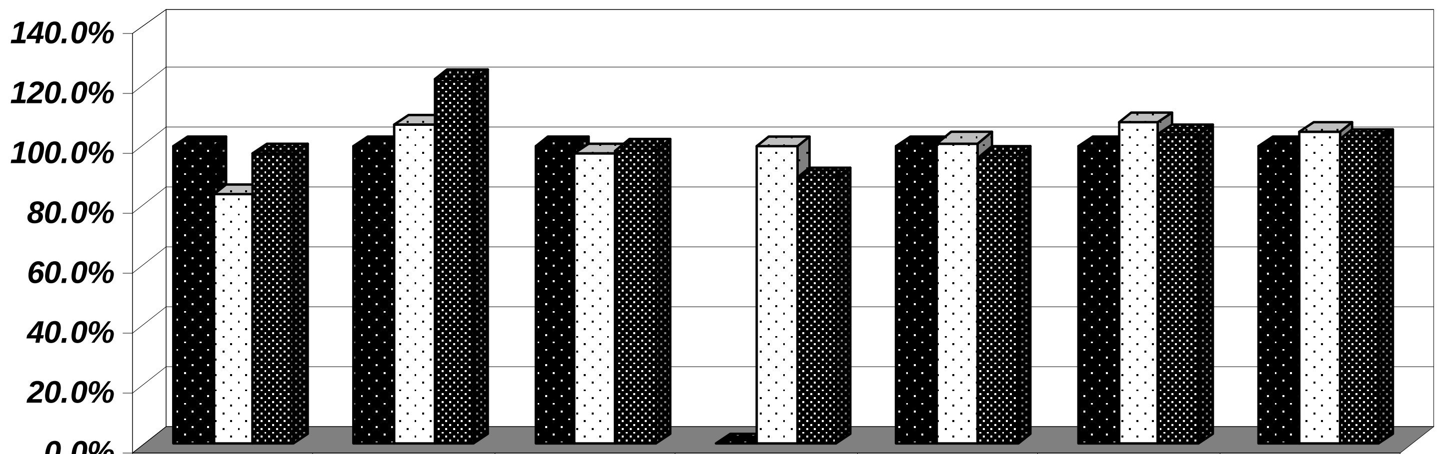
- Transport management strategies increase overall social welfare
- TS-DM is generally better than DM alone



	Travel time	Travel cost	Consumers' Surplus	Transport investors' profit*	Housing developers' profit	Producers' surplus	Welfare
■ Scenario 0	100.0%	100.0%	100.0%	0	100.0%	100.0%	100.0%
□ Scenario I	83.5%	107.1%	97.2%	100%	100.9%	107.8%	104.8%
▩ Scenario II	97.4%	122.4%	98.4%	89%	96.1%	103.6%	102.2%

Results

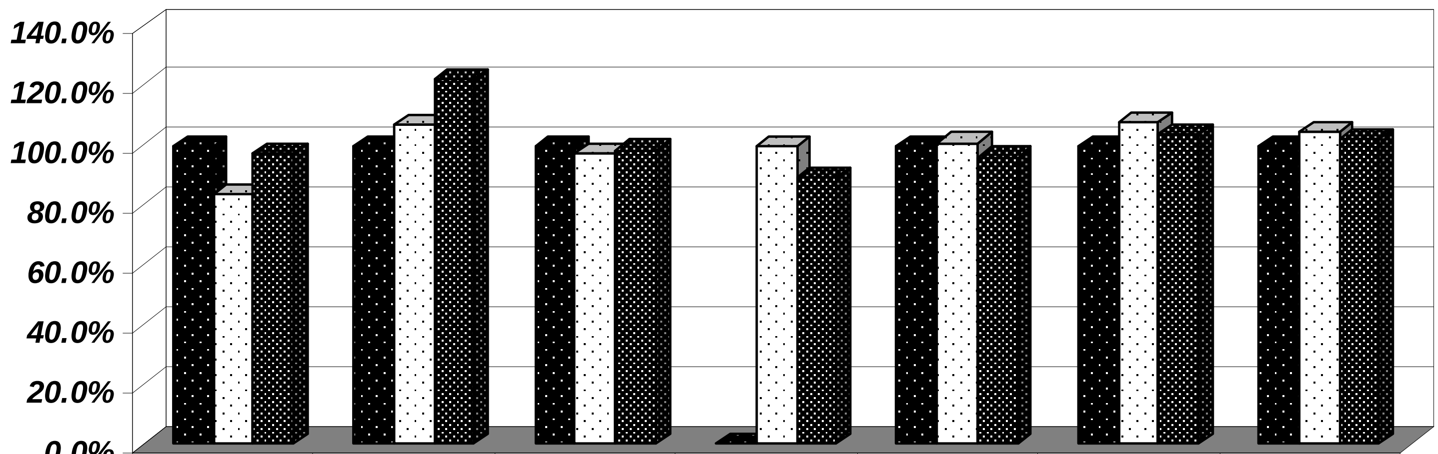
- Housing developer profit increases with TS-DM and decreases with DM alone



	Travel time	Travel cost	Consumers' Surplus	Transport investors' profit*	Housing developers' profit	Producers' surplus	Welfare
■ Scenario 0	100.0%	100.0%	100.0%	0	100.0%	100.0%	100.0%
□ Scenario I	83.5%	107.1%	97.2%	100%	100.9%	107.8%	104.8%
▩ Scenario II	97.4%	122.4%	98.4%	89%	96.1%	103.6%	102.2%

Results

- Travel time reduced through both transport strategies
- TS-DM is better than DM alone in congestion relief
- DM alone introduces higher travel costs
- Consumer surplus decreases



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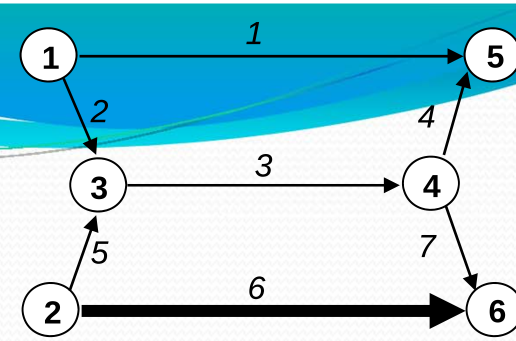
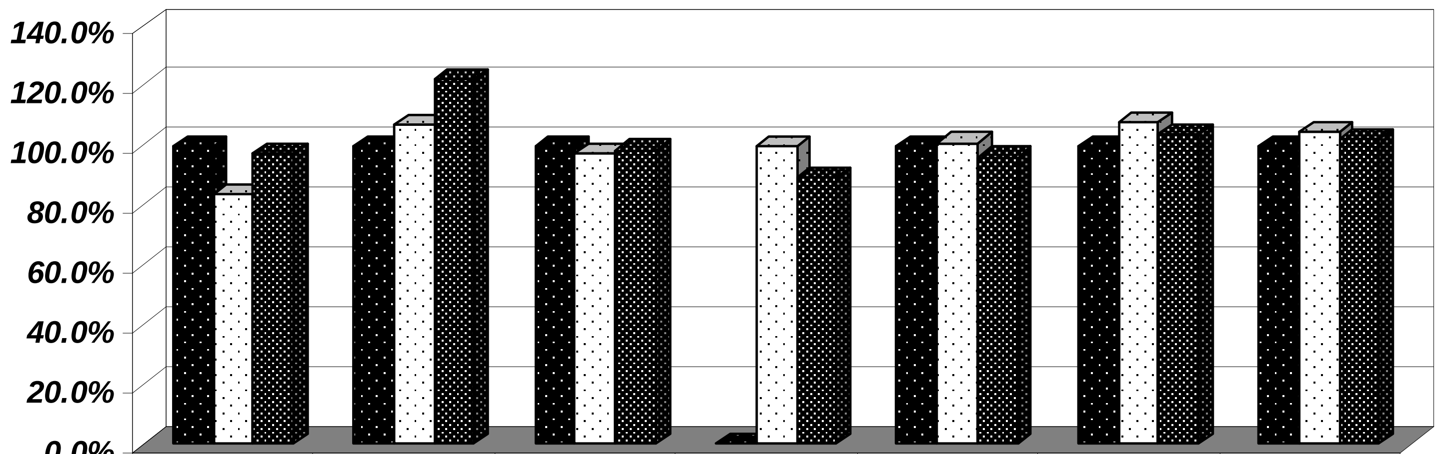
Results



- Overall system performance III
  - Congestion pricing brings revenue to transport investor
  - Housing developers may receive extra benefit from optimal TS-DM
  - They may also lose profit due to rent price reduction resulting from increased travel cost



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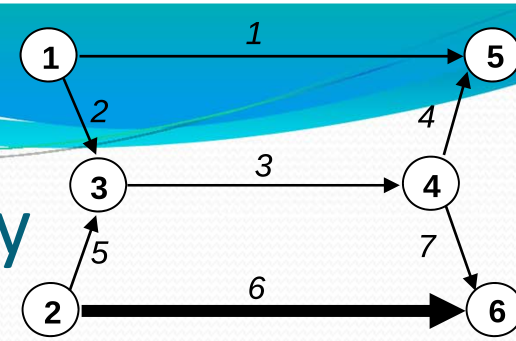
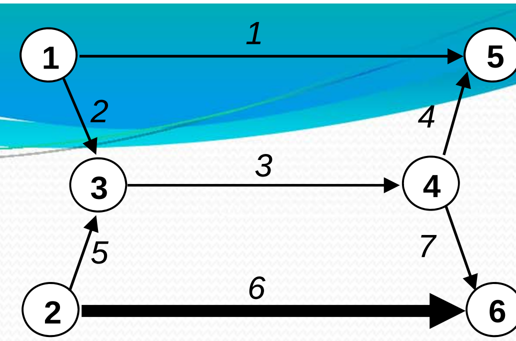
Sensitivity analysis of transport supply

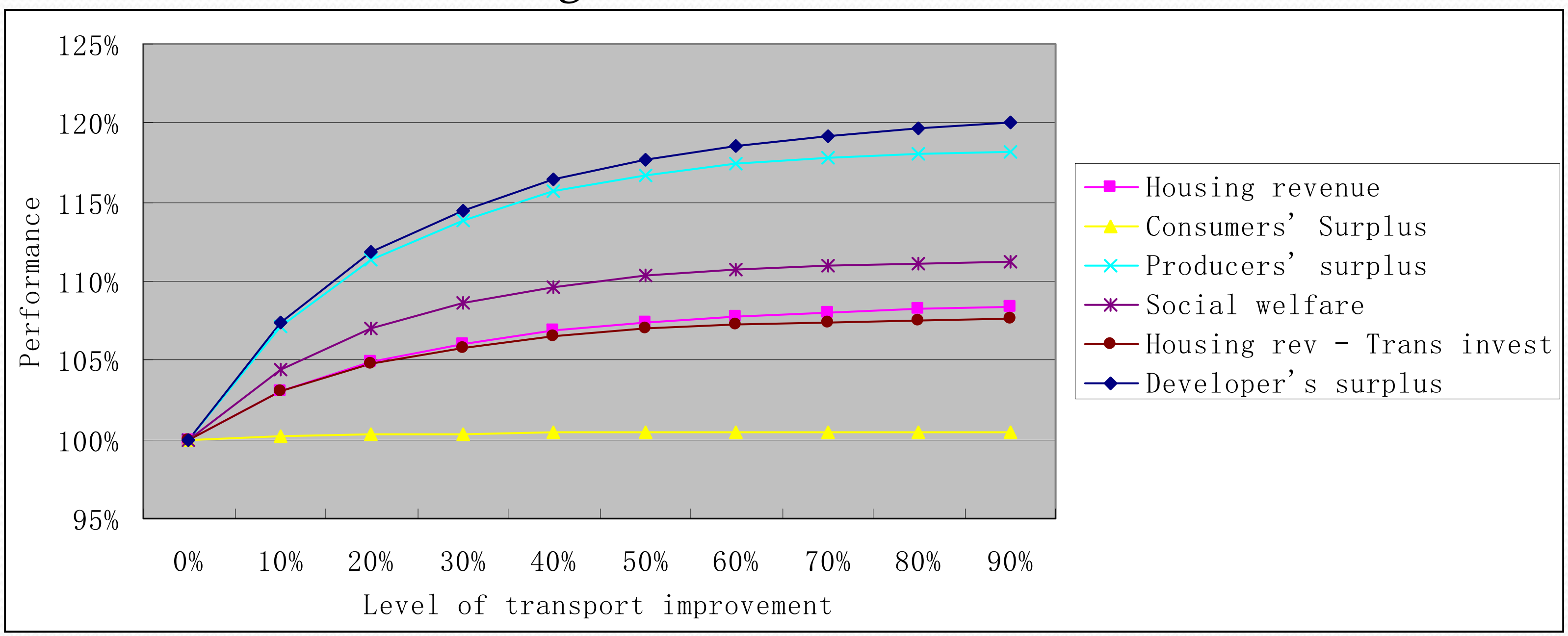


- Conduct the analysis for one period
- Fixed housing supply, workplace choice, and total demand
- Pure transport supply management but varying the levels of transport investment (overall highway capacities)
- Determine the resultant benefits to different stakeholders

Sensitivity analysis of transport supply



- Transport investment and Housing market
  - Developer surplus increases monotonically with transportation supply due to increasing housing rents
  - Consumers may benefit or suffer from transportation supply depending on the tradeoff between travel cost reduction and increased housing rents
  - The possibility of subsidizing transport investment from housing sale depends on the marginal travel cost reduction per unit capacity investment cost and the total housing demand.



Concluding remarks

- An analytical framework is developed to evaluate the impact of TS-DM strategies on residential location & travel choices, and the resultant housing value in an integrated land use and transport system.
- It also offers a platform to analyze the benefit and cost of different stakeholders.
- A stochastic bid-rent model is incorporated to model household's residential location choices.
- A quasi-dynamic structure is built to reflect the different time adaptabilities of residents' behaviors and infrastructure investments.
- The existence and uniqueness of the formulation is established by formulating two equivalent convex mathematical formulations.
- The overall problem is formulated as a MPEC, i.e. time-dependent transport strategies are optimized to achieve planning perspectives, subject to the equilibrium being equality constraints.

Concluding remarks

- Improvements in transportation cost would be transferred to higher willingness-to-pay and hence higher location bid-rents. Developers will always benefit from transportation supply
- On the other hand, pricing or demand management alone would likely hurt developers, due to reduced willingness-to-pay and hence lower housing rents. But the value of time needs to be carefully calibrated.
- Improvements in the transportation system due to TS-DM strategies may not always benefit consumers, depending on the relative magnitude between the resultant location bid-rent and reduced travel cost.
- A case is made for cross-subsidization between the windfall profit from transportation supply and the cost of this transportation supply (?)

Thank you!