Urban Structure, Land Prices and Volatility

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Motivating Observations

- Cities have very different house price/rent volatilities
- Avg office rent volatility between 1988-2014 (std. of log):
  - 5.71% in LA
  - 6.95% in Phoenix
  - 21.98% in New York
  - 20.52% in Dallas
- Commercial real estate tends to be more volatile than residential (Kwong and Leung 2000)
- City configurations also differ tremendously:
  - Houston (2016): population=2.3 million; area=1,553 km^2
  - NYC (2016): population=8.6 million; area=784 km^2

Questions

- How do city configuration and city land price dynamics depend on city characteristics?
- We consider a rich set of city characteristics:
  - transportation infrastructure
  - land/housing supply constraints
  - strength of production externality
  - relative share of capital, land, and labor in production

Approach

1. Construct a general equilibrium model and characterize the equilibria
   - perfect mobility of capital and labor across cities
   - monocentric circular cities
   - multiple equilibria may exist

2. Study comparative statics about land rent, wage and population
   - analytical results about land rent elasticities with respect to productivity

3. Simulate a dynamic model to study
   - land rent volatility
   - land rent serial correlation
   - rent to value ratio of land

Literature

- Theoretical
  - Glaeser et al. (2006): a simple model that assume land supply constraint $\Leftrightarrow$ supply elasticity
  - Saiz (2010) shows how supply constraint leads to low supply elasticity
  - We extend the simple model in Saiz (2010) in major ways:
    - allow for feedback from population growth to TFP
    - go beyond supply constraints to study a rich set of city characteristics
  - We show **land supply constraint doesn't necessarily lead to more volatile prices**
- Empirical
  - Focus on one city characteristic: land/house supply constraints
  - Glaeser et al. (2006), Saiz (2010), Hilber and Vermeulen (2016)

Model

- A monocentric circular city is occupied by firms and workers.
- Competitive firms operate in the CBD, produces tradable goods.
- Workers receive reservation utility and choose
  - consumption of tradable goods and land
  - location of residence
- Absentee landlords take all the economic surplus
- Transportation cost (j=distance; N=population):

$$f(j, N) = \beta_0 + \beta_1 j + \beta_2 jN$$

Workers

$$\max_{c,h} = u(c, h)$$

$s.t.$

$$c + p_r(j)h = w \times e^{-f(j,N)}$$

where

- c = non-tradable goods
- h = land
- w = wage
- $p_r(j)$ = land rent in location j
- $u(c, h) = c^{1-\theta} h^{\theta}$

Residential Bid-rent

- perfect labor mobility $\Rightarrow$ reservation utility $\underline{u}$
- In each location, the landlord charge a rental rate such that workers achieve the reservation utility

$$p_r(j) = \left[\frac{(1-\theta)^{1-\theta}\theta^{\theta}}{\underline{u}} we^{-f(j,N)} \right]^{1/\theta}$$

- the rent $p_r(j)$
  - increases with wage
  - decreases with transportation cost
  - decreases with reservation utility

Firms

$$\max_{\ell,n} F(\ell,k,n) - wn - rk - q_c\ell$$

$s.t.$

$$F(\ell,k,n) = A\ell^{\sigma}k^{\xi}n^{1-\sigma-\xi}$$

- k=capital, ℓ=land, n=labor
- r=capital rent, exogenous given
- A=TFP that firms take as given
- Firms take TFP as given, FOCs are

$$\frac{\ell}{n} = \frac{\sigma}{1-\sigma-\xi}\frac{w}{p_c}$$

$$\frac{k}{n} = \frac{\xi}{1-\sigma-\xi}\frac{w}{r}$$

$$\frac{\ell}{k} = \frac{\sigma}{\xi}\frac{r}{p_c}$$

Commercial Bid-rent

- perfect capital mobility + constant return to scale production function $\Rightarrow$ zero profit
- In CBD, the landlord change a rental rate of commercial land such that firms' profit is zero

$$p_c = \left[\frac{A\sigma^{\sigma}\xi^{\xi}(1-\sigma-\xi)^{1-\sigma-\xi}}{r^{\xi}w^{1-\sigma-\xi}} \right]^{\frac{1}{\sigma}}$$

- the rent $p_c(j)$
  - decreases with wage
  - increases with TFP

City Level Variables

- TFP: $A = \tilde{A}N^{\lambda}$, where
  - $\tilde{A}$=exogenous productivity
  - N=total number of workers (population)
  - λ = agglomeration parameter
- S = total area of CBD (pre-specified)
- K = total amount of capital (MPK=r)
- J = distance from CBD to city boundary ($p_r(J) = \underline{p}$)
  - $\underline{p}$ = agricultural land rent (exogenous)
- Λ = share of undevelopable residential land

General Equilibrium

- Three endogenous prices:
  - wage (w)
  - commercial land rent (p_c)
  - residential land rent (p_r)
- Four endogenous quantities: $\{N, K, J, A\}$
- Seven equations for seven endogenous variables
- General equilibrium can be summarized by two equations:
  - aggregate labor supply equation
  - aggregate labor demand equation

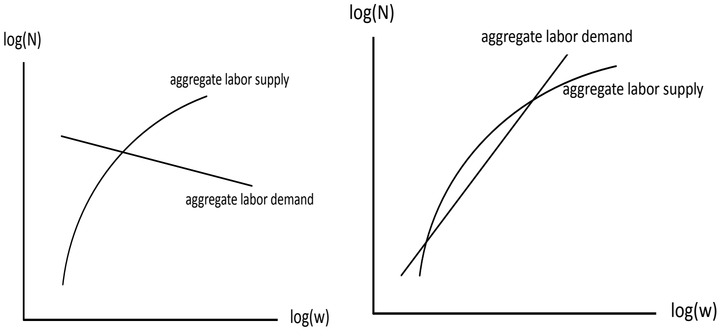
Aggregate Labor Supply

- A positive relationship between population and wage
- Derived from residential land market equilibrium
  - higher wage $\Rightarrow$ higher residential and rent (bid-rent)
  - higher rent $\Rightarrow$ more land in the periphery is developed
  - more land $\Rightarrow$ more workers are housed in the city

Aggregate Labor Demand

- The relationship between population and wage
- Derived from residential land market equilibrium
  - larger population $\Rightarrow$ higher TFP (agglomeration)
  - higher TFP $\Rightarrow$ firms can afford higher wage and land rent
  - Since land is immobile, land rent rises more quickly than wage, therefore higher TFP $\Rightarrow$ larger $\frac{N}{S}$
- The relationship can be positive if the agglomeration effect is strong enough.

Illustration of Equilibrium



(a) $\sigma > \lambda$

(b) $\sigma < \lambda < \sigma + (1 - \xi)\frac{2\theta}{1-\theta}$

- Ignoring congestion effect, the aggregate labor supply curve is a straight line, and equilibrium is always unique, e.g. Lucas and Rossi-Hansberg (2002).
- Whenever multiple equilibria exist, we focus on the good equilibrium.

Elasticities

- The economy starts from a steady state
- It receives an exogenous shock to productivity $\tilde{A}$
- It reaches a new steady state
- Changes between the two steady states are:
  - $\zeta_w = \frac{dw/w}{d\tilde{A}/\tilde{A}}$ = wage elasticity
  - $\zeta_N = \frac{dN/N}{d\tilde{A}/\tilde{A}}$ = population elasticity
  - $\zeta_{p_c} = \frac{dp_c/p_c}{d\tilde{A}/\tilde{A}}$ = commercial rent elasticity
  - $\zeta_{p_r(j)} = \frac{dp_r(j)/p_r(j)}{d\tilde{A}/\tilde{A}}$ =residential rent elasticity in location j
- elasticity $\approx$ volatility in the dynamic model

wage and Population Elasticities

$$\zeta_N = \frac{1}{-\lambda + \sigma + (1-\xi)F}$$

$$\frac{\zeta_w}{\zeta_N} = F$$

- F = cost of travelling from CBD to periphery
- larger F implies:
  - more increase in wage
  - less increase in population
- consistent with Glaeser et al. (2006)

Residential Rent

$$\zeta_{p_r} = \frac{1}{\theta} \times \frac{F - \beta_2 jN}{-\lambda + \sigma + (1-\xi)F}$$

where $\beta_2 jN$ is the congestion effect in transportation cost function.

- We can show that $\zeta_{p_r} > 0$ (unless the city can grow explosively), since
  - $F - \beta_2 jN > 0$
  - $-\lambda + \sigma + (1-\xi)F > 0$
- ζ_{p_r} decreases with distance to CBD, i.e., rent of close-in land is more volatile.

Residential Rent Elasticity and Production Function

$$\zeta_{p_r} = \frac{1}{\theta} \times \frac{F - \beta_2 jN}{-\lambda + \sigma + (1-\xi)F}$$

which is:

- increasing in λ and ξ but decreasing in σ in each location.
  - λ = agglomeration parameter
  - ξ = capital share in production
  - σ = land share in production
- decreasing in F if $\lambda - \sigma > (1-\xi)\beta_2 jN$; and increasing otherwise.

Residential Rent Elasticity and Undevelopable Land

Proposition

Among cities with more undevelopable land (i.e. larger Λ)

1. *have lower residential land rent elasticities if and only if* $\lambda - \sigma > (1 - \xi)\beta_2 jN$*, given the same population.*
2. *have a larger geographical size if and only if* $\lambda - \sigma < (1 - \xi)\beta_2 JN$*.*

Commercial Rent Elasticity

$$\zeta_{p_c} = \frac{1 + F}{-\lambda + \sigma + (1 - \xi)F}$$

which is:

- increasing in λ and ξ but decreasing in σ,
- decreasing in transportation cost F.

Elasticity: Commercial Land vs Residential Land

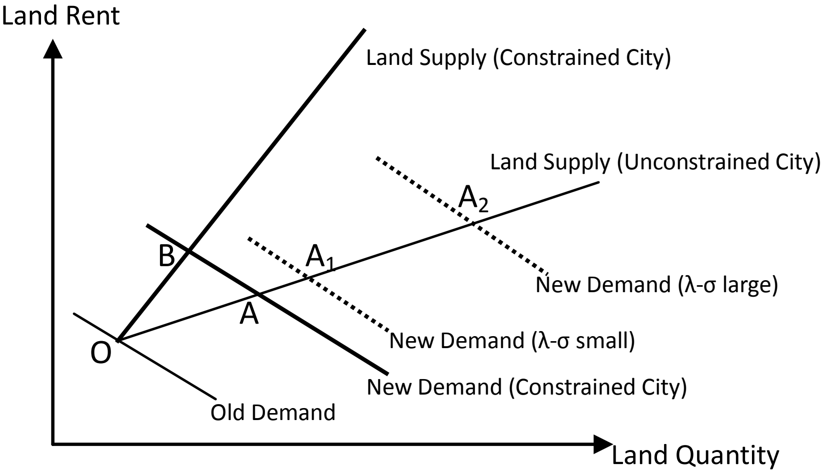
$$\zeta_{p_c} > \zeta_{p_r(j=0)} \quad \Leftrightarrow \quad F < \frac{\theta}{1-\theta}$$

Low transportation cost F (relative to $\frac{\theta}{1-\theta}$ which measure the

importance of land consumption)

- $\Rightarrow$ easy to develop new residential land in periphery
- $\Rightarrow$ residential land supply is elastic

Supply Constraint and Rent Elasticity



Model Extensions (Proposition 6 in the paper)

Proposition

Relative to the benchmark model, the following is true:

1. *fixing the city boundary,*
   1.1 *residential land rent elasticity is lower if* $\lambda - \sigma > \beta_2 jN(1-\xi)$ *for all* j*,*
   1.2 *commercial land rent elasticity is lower if* $\lambda - \sigma > -(1-\xi)$*.*
2. *allowing the CBD to expand and contract, land rent elasticity is higher than the benchmark model if and only if* $F < \frac{\theta}{1-\theta}$*.*
3. *assuming immobile capital (i.e. fixing the city-level capital stock), both commercial land and residential land have lower rent elasticities.*

Dynamic Model

$$
\begin{aligned}
A_t &= \tilde{A}_t N_{t-1}^{\lambda} \\
\log \tilde{A}_t &= \log \tilde{A}_{t-1} + \epsilon_t, \\
\epsilon_t &\sim \mathcal{N}(0, \sigma_\epsilon^2)
\end{aligned}
$$

- The agglomeration effect on productivity depends on lagged city population.
- Rise and fall of cities are persistent due to the lagged feedback.
- With the dynamic model, we study
  - serial correlation of land rent
  - land rent-to-value ratios
  - land rent volatilities

Calibration

Parameter Values

Symbol	Definition	Value
σ_ϵ	stdev. of productivity shocks	0.003
θ	land share in preference	0.3
ξ	capital share in production	0.2
$\underline{u}$	reservation utility	0.118
$\underline{p}$	agricultural rent (per $100km^2$)	0.447
$\tilde{A}$	initial productivity	2.735

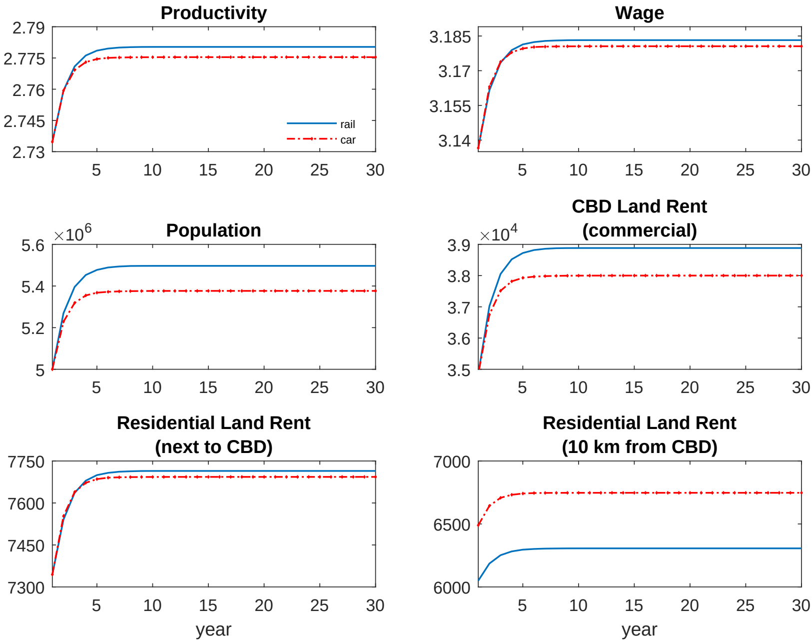
Commuting Cost

$$\begin{aligned} f(j, N, \tau = car) &= 0.0073 + 0.00008 \times j + 2.2e-9 \times j \times N \\ f(j, N, \tau = rail) &= 0.0201 + 0.0005 \times j + 8.0e-10 \times j \times N \end{aligned}$$

Initial City Configuration

	Pop (*million*)	*CBD* (km^2)	*Radius* (*km*)	Wage	p_c ($100m^2$)	p_r ($100m^2$)	*Density* ($pop/100m^2$)
λ**=0.08**							
σ**=0.05**							
$\Lambda = 0.0$	5.00	30	16.00	3.14	3.49	0.73	62.20
$\Lambda = 0.4$	3.88	30	18.28	3.11	2.68	0.71	61.66
λ**=0.076**							
σ**=0.15**							
$\Lambda = 0.0$	1.72	30	9.79	2.82	3.73	0.52	57.06
$\Lambda = 0.4$	1.58	30	12.09	2.84	3.46	0.53	57.41

Transition



Productivity
2.79
2.775
2.76
2.745
2.73
5
10
15
20
25
30
rail
car
Wage
3.185
3.17
3.155
3.14
5
10
15
20
25
30
Population
$\times 10^6$
5.6
5.4
5.2
5
5
10
15
20
25
30
CBD Land Rent
(commercial)
$\times 10^4$
3.9
3.8
3.7
3.6
3.5
5
10
15
20
25
30
Residential Land Rent
(next to CBD)
7750
7600
7450
7300
5
10
15
20
25
30
year
Residential Land Rent
(10 km from CBD)
7000
6500
6000
5
10
15
20
25
30
year

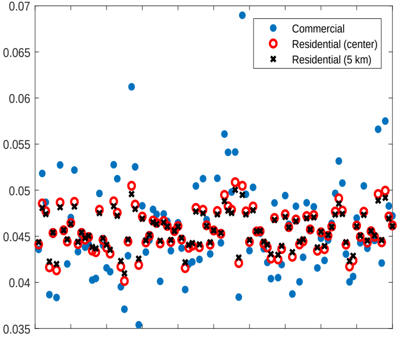
Serial Correlation

λ=0.08, σ=0.05	p_c	p_r (j=0)	p_r (j=5)
Baseline	0.366	0.356	0.357
Rail	0.455	0.432	0.433
Λ=0.4	0.391	0.380	0.381
Fix capital	0.139	0.139	0.139
Fix boundary	0.131	0.131	0.132
λ=0.076, σ=0.15			
Baseline	0.357	0.351	0.351
Rail	0.386	0.380	0.379
Λ=0.4	0.345	0.342	0.342
Fix capital	0.126	0.125	0.125
Fix boundary	0.100	0.100	0.100

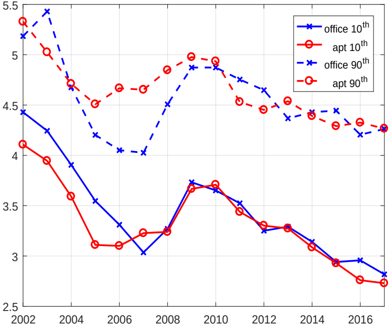
Volatility (std. of log)

λ=0.08, σ=0.05	$\tilde{A}$	*Wage*	*Pop*	p_c	p_r $j=0$	p_r $j=5$
Baseline (Car)	1.849	1.715	9.564	11.276	5.715	4.780
Rail	2.161	1.847	13.712	15.552	6.158	5.180
$\Lambda = 0.4$ (car)	1.869	1.694	10.286	11.977	5.647	4.861
Fix capital (car)	1.354	0.577	3.110	3.686	1.922	1.610
Fix boundary (car)	1.341	1.493	2.944	4.437	4.976	4.679
λ=0.076, σ=0.05						
Baseline (car)	2.707	2.059	21.348	23.387	6.863	5.586
λ=0.076, σ=0.15						
Baseline (car)	1.840	0.469	9.765	10.233	1.564	1.219
Rail	1.935	0.349	11.044	11.392	1.163	0.908
$\Lambda = 0.4$ (car)	1.805	0.512	9.307	9.818	1.708	1.406
Fix capital (car)	1.333	0.300	2.952	3.252	0.999	0.813
Fix boundary (car)	1.293	1.165	2.405	3.570	3.882	3.712

Dispersion of Rent-to-value Ratios



(c) model



(d) data

Rent-to-value Ratios

λ=0.08 σ=0.05	10^{th} **percentile**			90^{th} **percentile**			**Dispersion** $100 \times (90^{th} - 10^{th}) / mean$		
	L_c	L_r (j=0)	L_r (j=5)	L_c	L_r (j=0)	L_r (j=5)	L_c	L_r (j=0)	L_r (j=5)
Baseline	4.01	4.25	4.60	5.27	4.87	4.83	27.32	13.54	4.70
Rail	3.85	4.24	4.60	5.72	4.92	4.86	39.18	14.90	5.41
Λ=0.4	3.91	4.24	4.61	5.40	4.88	4.84	31.98	13.98	4.89
Fix K	4.36	4.46	4.58	4.74	4.65	4.66	8.24	4.28	1.76
Fix J	4.32	4.29	4.59	4.77	4.79	4.84	9.89	11.09	5.16
λ=0.076 σ=0.15									
Baseline	4.01	4.48	4.58	5.11	4.64	4.63	24.14	3.49	1.14
Rail	3.95	4.50	4.57	5.17	4.62	4.62	26.75	2.60	0.89
Λ=0.4	4.04	4.47	4.58	5.09	4.65	4.64	23.08	3.85	1.25
Fix K	4.39	4.51	4.57	4.72	4.61	4.61	7.25	2.22	0.89
Fix J	4.36	4.35	4.59	4.74	4.74	4.78	8.31	8.54	4.19

Conclusion

- We develop a framework for thinking about how design of a city and the firms that inhabits it affect its
  - configuration
  - land values
  - risk of real estate.
- large λ (agglomeration) + small σ (land share in production) $\Rightarrow$
  - high density, high wage, large population (e.g. NYC)
  - high volatility and large serial correlation in rent
  - more dispersion in rent-to-value ratio
- Land supply constraints do not necessarily lead to more land rent volatility, because constraints
  - suppress agglomeration effect
  - cause land demand curve to be shifted less.

Future Work

- Add buildings and adjustment cost to the model:
  - Study the endogenous response of real estate development to house price volatility
  - House price volatility is a fixed point
- Allow multiple CBDs to arise endogenously (lot of implications on Chinese cities)
- Consider migration costs of labor
  - Workers in rising cities receives higher utility then workers in falling cities.
  - Implications on labor misallocation (Hseih and Moretti 2017)