Macroeconomic Implications of Agglomeration

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Big picture

1. Cities exist because of agglomeration externalities.
2. Most production (and therefore growth) occurs in cities.
3. How important is agglomeration for aggregate growth?

How do we answer the question?

1. Write down a general equilibrium model of cities and aggregate growth.
2. Characterize the balanced growth path.
3. Use FOC of the model to estimate impact of agglomeration on local productivity with panel data.
4. Quantify the percentage per-capita consumption growth attributable to agglomeration.

Key findings

Balanced growth path:

$$\gamma_c = \gamma \, \tau^{\frac{\delta-1}{(1-\alpha)\delta}}$$

With $\delta = 1.02$ and $\tau = 2.8\%$

Data	γ_c	α	ϕ	$\delta = \phi$ $\hat{\gamma}_c$	Inc. in γ_c Due to Density
C	1.11%	0.30	0.99	1.01%	11.7%

Model: Cities, firms, production

Environment

- Time discrete.
- Unit measure of locations called "cities"
- Cities indexed by state (s, z).
  - s is beginning-of-period stock of developed land. Land used for housing workers and firm production.
  - z is exogenous city-specific productivity.
  - $Q(z, z')$ is prob z' occurs next period given z today.

Intermediate goods producers

- Competitive firms produce intermediate good unique to each city

$$y = a \; l_b^{1-\phi} \; k_b^{\alpha\phi} \; n^{(1-\alpha)\phi}$$

  - a is TFP
  - l_b is land used for production
  - k_b is business capital
  - n is labor

Intermediate goods producers

- TFP taken by firms as given:

$$a = z^{(1-\alpha)\phi} \left(\frac{Y}{L_b}\right)^{\frac{\lambda-1}{\lambda}}$$

  - Y is total city output.
  - L_b is total developed land in the city used in production.

- This is the density externality proposed by Ciccone-Hall (1996)

Final goods, land, housing producers

- Final goods producers aggregate city goods:

$$\bar{Y}_t = \left[\int y(s,z)^{\eta} \mu_t (ds, dz) \right]^{\frac{1}{\eta}}$$

Final good can be used for consumption, investment in new capital, investment in new land

- Land developers augment stock of developed land according to:

$$s_{t+1} = \zeta(s_t, x_t)$$

- Housing firms provide housing services according to:

$$h = k_h^{\omega} \, l_h^{1-\omega}$$

Land development firms

Land developers in each city

- rent developed land
- augment the stock of developed land

$$W(s,z) = \max_{\{s',x\}} p^l(s,z)s - vx + \frac{1}{R}\int W(s',z')Q(z,z')dz'$$

Discussion of land

- In the Rossi-Hansberg and Wright (2006) model of growth and cities:
  - Production occurs at a CBD (point in the center of a circle)
    - Firms do not use land for production
    - Can not consider a density externality
    - Production subject to a human capital externality
  - Households demand 1 unit of land
    - Land differentiated by distance to CBD
  - Cities expand by adding land for new residences farther away from CBD
    - City population limited by commuting costs

Discussion of land

- In this paper land plays a very different role
  - All land in an MSA is identical
  - Land is a valued input to production and housing
  - No idea of distance: Production and housing occur anywhere in a city
  - City can expand by adding more land (which is costly)
    - This new land can be used for production or housing
- Captures idea that cities expand by adding jobs and housing at edge
- Explicitly allows output density to vary across places and over time

Prices and markets

- Goods/services traded in economy-wide markets

Good	Price
Final goods	1
Intermediate goods	$q(s, z)$
Rent on capital	r
New land investment goods	v

- Goods/services traded in local markets

Good	Price
Rent on land	$p^l(s, z)$
Labor services	$w(s, z)$
Rent on housing	$p(s, z)$
Purchase price of developed land	$b(s, z)$

Profit Maximization

$$
\begin{aligned}
rk_b(s,z) &= \alpha\phi q(s,z)y(s,z) \\
w(s,z)n(s,z) &= (1-\alpha)\phi q(s,z)y(s,z) \\
p^l(s,z)l_b(s,z) &= (1-\phi)q(s,z)y(s,z)
\end{aligned}
$$

$$
p^l(s,z) = \omega^{\frac{\omega}{1-\omega}}(1-\omega)p(s,z)^{\frac{1}{1-\omega}}r^{\frac{-\omega}{1-\omega}}
$$

$$
\begin{aligned}
b(s,z) &= \frac{1}{R}\int\left[p^l(s',z') + b(s',z')\zeta_1(s_{t+1},x_{t+1})\right]Q(z,z')dz' \\
v &= \zeta b(s,z) = \zeta_2(s_t,x_t)
\end{aligned}
$$

Market Clearing

$$
\begin{aligned}
n(s,z)k_h(s,z) + k_b(s,z) &= k(s,z) \\
n(s,z)l_h(s,z) + l_b(s,z) &= s \\
\int k(s,z)\mu_t(ds,dz) &\leq K_t \\
\int n(s,z)\mu_t(ds,dz) &\leq 1 \\
C_t + K_{t+1} - (1-\kappa)K_t + v_t \int x(s,z)\mu_t(ds,dz) &\leq \bar{Y}_t
\end{aligned}
$$

Balanced growth

- From aggregate resource constraint
  - Per capita C, K, $v \int x(s,z)$, $\bar{Y}$ all increase at same rate: γ_c
- Assumption: All cities increase at same rate
  - Per capita y, k increases at same rate for all cities: γ_c
  - Per capita s, x increase at same rate for all cities: γ_c/τ
- From within-city resource constraints
  - Per capita k_b, k_h increase at same rate within each city: γ_c
  - Per capita l_b, l_h increase at same rate within each city: γ_c/τ

Balanced growth rates

$$y = z^{(1-\alpha)\phi} \left(\frac{Y}{L_b}\right)^{\frac{\lambda-1}{\lambda}} l_b^{1-\phi} k_b^{\alpha\phi} n^{(1-\alpha)\phi}$$

$$y/n = z^{(1-\alpha)\phi} \left(\frac{Y/n}{L_b/n}\right)^{\frac{\lambda-1}{\lambda}} (l_b/n)^{1-\phi} (k_b/n)^{\alpha\phi}$$

$$\gamma_c = \gamma^{(1-\alpha)\phi} \left(\frac{\gamma_c}{\gamma_c/\tau}\right)^{\frac{\lambda-1}{\lambda}} (\gamma_c/\tau)^{1-\phi} \gamma_c^{\alpha\phi}$$

$$\gamma_c = \gamma\tau^{\frac{\delta-1}{(1-\alpha)\delta}}$$

Next steps

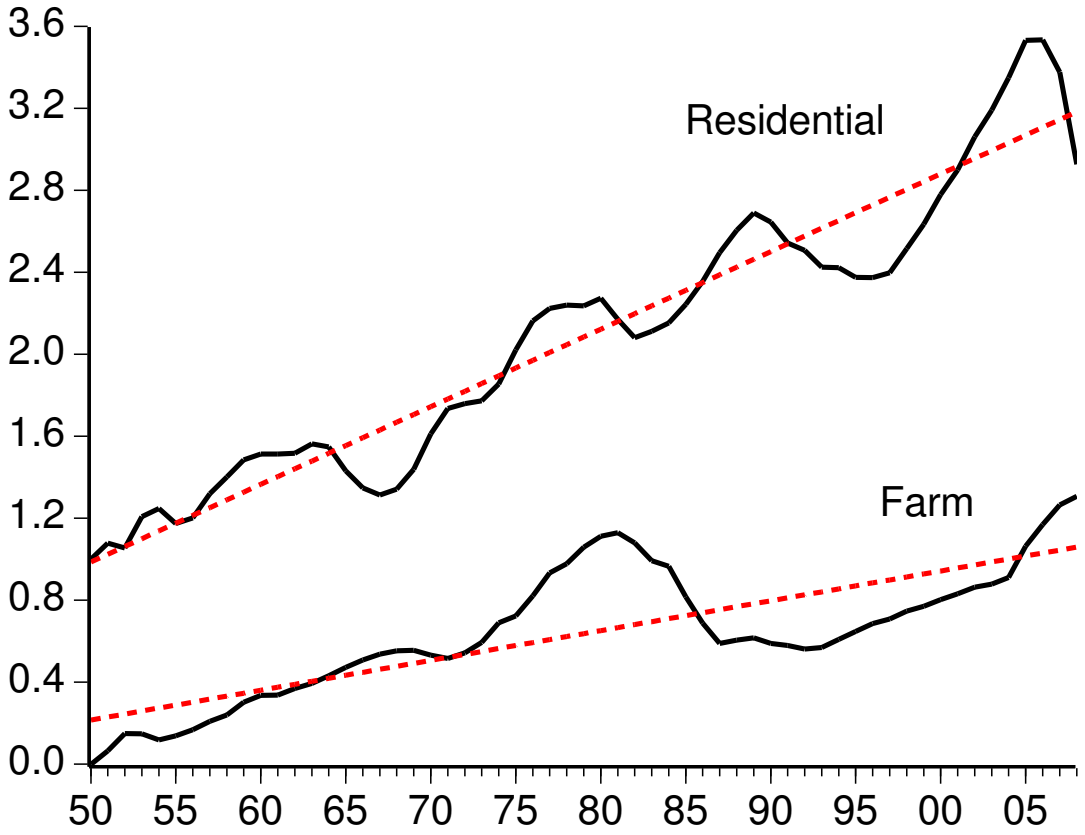
$$\gamma_c \quad = \quad \gamma \tau^{\frac{\delta-1}{(1-\alpha)\delta}}$$

1. Estimate τ using available data on residential land prices
2. Use τ, model, and macro data to calibrate γ_c, α, ϕ, ω
3. Given α and ω, estimate $\delta = \phi\lambda$
4. Compute counterfactual: $\hat{\gamma}_c$ assuming $\lambda = 1.0$ as $\gamma_c \quad = \quad \gamma \tau^{\frac{\phi-1}{(1-\alpha)\phi}}$

Estimating τ

- Use growth of developed land prices to measure τ
- If developed land is not shrinking, have upper bound:
  $\tau = \gamma_c \mu = 1.031$
  (μ is population growth rate)
- Farm land price growth 1950-2008 as lower bound: 1.026
- Residential land price growth (Davis & Heathcote (2007))
  - 1951-2008: 3.8%
  - 1980-2008: 2.8%

Real land prices, 1950-2008



Calibrating α, ϕ, ω

(α, ϕ)

- Solve non-labor share of income $1 - \phi + \alpha\phi$ and share of non-labor income attributable to land $\frac{1-\phi}{1-\phi+\alpha\phi}$
- estimate land's share of income using share of **value** from flow of funds and converting to income share using intertemporal conditions for land and capital
- Yields (α, ϕ) of (0.30,0.99)

$1 - \omega$

- Use lands share of housing **value** and convert to income share using intertemporal conditions for land and capital
- 1950-2008: 0.27, $\omega = 0.89$
- 1980-2008: 0.35, $\omega = 0.85$

Estimating δ

- FOC of intermediate goods producers implies:

$$\frac{w_i}{w_j} = \frac{z_i}{z_j}\left[\frac{p_i^l}{p_j^l}\right]^{\frac{\delta-1}{\delta(1-\alpha)}}\left[\frac{q_i}{q_j}\right]^{\frac{1}{\delta(1-\alpha)}} \tag{1}$$

- The FOC of housing services providers implies:

$$\frac{p_i^l}{p_j^l} = \left[\frac{p_i}{p_j}\right]^{\frac{1}{1-\omega}} \tag{2}$$

Estimating δ

- Combining (1) and (2):

$$\frac{w_i}{w_j} = \frac{z_i}{z_j}\left[\frac{p_i}{p_j}\right]^{\frac{1}{1-\omega}\frac{\delta-1}{\delta(1-\alpha)}}\left[\frac{q_i}{q_j}\right]^{\frac{1}{\delta(1-\alpha)}}$$

- Take logs. Express log deviation from average as a "hat"

$$\hat{w}_i = \left[\frac{1}{1-\omega}\right]\underbrace{\left[\frac{\delta-1}{\delta(1-\alpha)}\right]}_{\text{Coef. of Interest}}\hat{p}_i + \left[\frac{1}{\delta(1-\alpha)}\right]\hat{q}_i + \hat{z}_i$$

- Implies wages are relatively high if:
  - TFP is high ($\hat{z}_i$)
  - Price of city output is high ($\hat{q}_i$)
  - Price of land and housing is high ($\hat{p}_i$)

Extension: 2 types of workers

- Of course: high wage cities may be high human capital cities
- Model extension: two types of workers, high and low skill

$$n_i = \left[\sigma n_{ui}^{\xi} + (1-\sigma) n_{ei}^{\xi}\right]^{1/\xi}$$

- The relative wage paid to high-skill workers is $\hat{w}_{ei}$

$$= \left[\frac{1}{1-\omega}\right]\left[\frac{\delta-1}{\delta(1-\alpha)}\right]\hat{p}_i + \left[\frac{1}{\delta(1-\alpha)}\right]\hat{q}_i + \left[\frac{1-\xi}{\xi}\right]\hat{\chi}_i + [\xi-1]\,\hat{m}_i + \hat{z}_i$$

$$\begin{aligned} \chi_i &= \frac{w_{ei} n_{ei} + w_{ui} n_{ui}}{w_{ui} n_{ui}} \\ m_i &= \frac{n_{ei}}{n_{ui}} \end{aligned}$$

Endogeneity

$$\hat{w}_{ei} = \left[\frac{1}{1-\omega}\right]\left[\frac{\delta-1}{\delta(1-\alpha)}\right]\hat{p}_i + \left[\frac{1}{\delta(1-\alpha)}\right]\hat{q}_i + \left[\frac{1-\xi}{\xi}\right]\hat{\chi}_i + [\xi - 1]\,\hat{m}_i + \hat{z}_i$$

- $\hat{z}$ correlated with everything. Cannot run regression
- 2 possible strategies using IV:
  - "Long lags"
  - Specify process for $\hat{z}$ (need a panel)
- We do the latter, use Arellano-Bover (1995) technique

Basic idea of Arellano-Bover

- Have some 1st order conditions from some model:

$$Y_t = \alpha + \beta X_t + z_t$$

- z_t is an AR(1) process: u_t iid

$$z_t = z_0 + \rho z_{t-1} + u_t$$

Basic idea of Arellano-Bover

1. Exploit the panel dimension of the data as follows:

$$\begin{array}{rcccccc} Y_t & = & \alpha & + & \beta X_t & + & z_t \\ \rho Y_{t-1} & = & \rho\alpha & + & \rho\beta X_{t-1} & + & \rho z_{t-1} \\ \rightarrow Y_t - \rho Y_{t-1} & = & \alpha(1-\rho) & + & \beta\left[X_t - \rho\beta X_{t-1}\right] & + & z_0 + u_t \end{array}$$

2. First-difference[1] to remove the "fixed effect" $\alpha(1-\rho) + z_0$

$$\Delta Y_t - \rho\Delta Y_{t-1} = \beta\left[\Delta X_t - \rho\beta\Delta X_{t-1}\right] + \Delta u_t$$

[1] When more than 2 waves of data are available, the Arellano-Bover procedure does not use a simple first difference.

Basic idea of Arellano-Bover

$$\Delta Y_t - \rho \Delta Y_{t-1} \;=\; \beta \left[\Delta X_t - \rho \beta \Delta X_{t-1} \right] \;+\; \Delta u_t$$

- Error term Δu_t is still correlated with Xs. Since u_t is iid, we potentially have good instruments:
  - Any variable dated $t-2$ or earlier is a potential instrument
  - In practice, use all model variables dated $t-3$ and $t-4$
- Use GMM to estimate ρ and β.

Data

- We construct annual panel data from 1985-2006 on 22 large MSAs covering 36 percent of the population
- High-skill hourly wage rates $\hat{w}_{ei}$, compensation ratios $\hat{\chi}_i$, and skill ratios $\hat{m}$ are derived using CPS data
- We construct relative output price measures $\hat{q}_i$ by merging data from the BEA regional and industry accounts
- We construct rental prices for housing using data from the BLS and from the 1990 Decennial Census of Housing

Standard deviations and correlations

Variable	Standard Deviation	Correlation with: $\hat{w}_{eit}$	$\hat{p}_{it}$	$\hat{q}_{it}$	$\hat{\chi}_{it}$	$\hat{m}_{it}$
$\hat{w}_{eit}$	0.082	1.00	0.46	-0.03	0.43	0.21
$\hat{p}_{it}$	0.181		1.00	0.49	0.46	0.34
$\hat{q}_{it}$	0.052			1.00	0.23	0.14
$\hat{\chi}_{it}$	0.172				1.00	0.91
$\hat{m}_{it}$	0.224					1.00

Some simple regressions

Dependent Variable: $\hat{w}_{eit}$		Dependent Variable: $\Delta\hat{w}_{eit}$	
$\hat{p}_{it}$	0.185 (0.039)	$\Delta\hat{p}_{it}$	0.148 (0.103)
$\hat{q}_{it}$	-0.241 (0.153)	$\Delta\hat{q}_{it}$	0.454 (0.554)
$\hat{\chi}_{it}$	0.571 (0.043)	$\Delta\hat{\chi}_{it}$	0.512 (0.044)
$\hat{m}_{it}$	-0.349 (0.035)	$\Delta\hat{m}_{it}$	-0.304 (0.034)
N	484		462
R^2	0.79		0.37

Implications of coefficient estimates

- Suppose $\omega = 0.85$. Then:

$$\left[\frac{1}{1-\omega}\right] \quad \left[\frac{\delta - 1}{\delta(1-\alpha)}\right] = 0.185$$

$$\underbrace{\frac{\delta - 1}{\delta(1-\alpha)}}_{\substack{\text{Coef. in} \\ \text{Growth Formula}}} = 0.0278$$

Note: If $\alpha = 0.3$ then $\delta = 1.020$

GMM parameter estimates and standard errors, $\alpha = 0.3$

Parameter	$\omega = 0.85$	$\omega = 0.89$
δ	**1.020**	**1.015**
	(0.002)	(0.002)
ξ	0.563	0.563
	(0.004)	(0.004)
ρ	0.569	0.572
	(0.010)	(0.010)
J-test	36.0	36.0
p-value	1	1
m2 test	-0.13	-0.14
p-value	0.45	0.45

Notes: The J-tests have 167 degrees of freedom.

GMM results

- With $\alpha = 0.3$ and $\omega = 0.85$ we estimate $\delta = 1.020$
  SE indicate $\delta > 1$
- With $\phi = 0.99$ then $\lambda = 1.03$
- $\rho = 0.57$. We were expecting an estimate of 0.90 or above
  Suggests city-specific shocks less persistent than aggregate shocks
- $\xi = 0.563$. Gives EOS of low- and hi-skill of 2.3

Monte Carlo study

- Blundell and Bond (2000) and Windmeijer (2005) suggest parameters and standard errors may be biased
- We were concerned that our ρ has a downward bias (Hurwicz) and that our standard errors may be biased down
- We ran a Monte Carlo study using our data. Results:
  - Our parameters are unbiased
  - Our standard errors are too low by about a factor of 2
    Even with this correction, we soundly reject $\delta = 1$

Percent of consumption growth due to agglomeration

$$\gamma_c = \gamma \, \tau^{\frac{\delta-1}{(1-\alpha)\delta}}$$

Baseline	$\omega = 0.89$	$\delta = 1.055$
11.7	9.6	28.0

Suppose no growth of land

$$\gamma_c = \gamma^{\frac{(1-\alpha)\delta}{1-\alpha\delta}} \mu^{\frac{\delta-1}{1-\alpha\delta}}$$

Baseline	$\omega = 0.89$	$\delta = 1.055$
12.6	10.4	30.0