Agglomeration and Transport Costs*

Urban Economics: Week 4

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30th and 31st January 2012

*I thank Kurt Schmidheiny for sharing his slides on "Measuring Agglomeration"

Agglomeration Economies

- Density generates costs
  - Higher cost of land
  - Greater congestion, higher commuting and transport costs
- Population and economic activity are ever more conentrated in cities
- There must be offsetting benefits
  - Higher productivity for firms
  - Higher wages for workers
- Are these advantages due to agglomeration economies?
- What are their scale and scope and causes?

The Concentration of Firms

- Why is it profitable for firms to concentrate employment?

1. Plant-level economies of scale
   - Plants produce more efficiently at a larger scale
2. Agglomeration economies
   - Plants produce more efficiently when close to other plants
   1. Urbanization economies
      - when close to other plants in general
   2. Localization economies
      - when close to other plants in the same industry
   3. Co-localization economies
      - when close to other plants in a particular other industry

Evidence of Agglomeration Economies

- Better theories of agglomeration economies than empirics
  - E.g., *Handbook of Regional and Urban Economics*, vol. 4: Duranton and Puga (2004) vs. Rosenthal and Strange (2004)
- Some economists don't believe in agglomeration economies at all

Three broad strategies to identify agglomeration economies

1. Show there is too much spatial concentration for location to be random or merely reflect natural advantages
2. Compare wages and rents across space
3. Compare productivity across space

The Spatial Impossibility Theorem

Theorem (Starrett 1978)

Consider an economy with a finite number of locations, of consumers, and of firms. Suppose that

1. *Transportation is costly;*
2. *Space is homogeneous;*
3. *There are no economies of scale.*

Then there is no competitive equilibrium involving transportation; instead, each location is self-sufficient.

- Substantial spatial concentration of economic activity is suggestive of agglomeration economies

Concentration Without Agglomeration Economies

1. Plant-level economies of scale
   - Lumpiness from small-scale indivisibilities in the production process
   - Most technologies require plants within a certain size range
2. Space is not homogeneous
   - Natural advantages: waterways, mines, etc.
   - "First-nature" determinants of location

- Concerns about natural advantages prevent estimation of urbanization economies
- Focus on identifying localization economies
  - Excessive concentration compared to aggregate economic activity
  - Explicit controls for industry-specific natural advantages

Measuring Localization

Five desirable properties of a localization measure

1. Comparable across industries
2. Controls for the concentration of overall economic activity
3. Controls for industrial concentration (distribution of plant sizes)
4. Avoids ex ante aggregation of points on a map into units in boxes ("modifiable areal unit problem")
5. Accompanied by a measure of statistical significance.

- Ellison and Glaeser (1997) satisfy 1–3
- Duranton and Overman (2005) add 4–5
    - Data-intensive improvement

The Dartboard Approach

- N darts thrown sequentially onto a board divided into M regions
- The k-th dart has mass z_k
  - Normalized so that $\sum_{k=1}^{N} z_i = 1$
  - Herfindahl index $H \equiv \sum_{k=1}^{N} z_i^2$
- Region i has area x_i
  - Normalized so that $\sum_{i=1}^{N} x_i = 1$
- With probability γ a dart follows its immediate predecessor
- With probability $1 - \gamma$ it hits the board randomly
  - It lands in region i with probability x_i
- The eventual mass of region i is $s_i = \sum_{k=1}^{N} z_k u_{ki}$
  - u_{li} is an indicator for dart k landing in region i

Concentration on the Dartboard

- Imbalance of endogenous mass and exogenous area

$$G \equiv \sum_{i=1}^{M} \left(s_i - x_i\right)^2$$

- In expectation

$$\begin{aligned} \mathbb{E}G &= \sum_{i=1}^{M} \left[Var\left(s_i\right) + \left(\mathbb{E}s_i - x_i\right)^2 \right] \\ &= \sum_{i=1}^{M} \left[\begin{array}{r} \sum_{k=1}^{N} z_k^2 Var\left(u_{ki}\right) + \sum_{k=1}^{N} \sum_{l \neq k} z_k z_l Cov\left(u_{ki}, u_{li}\right) \\ + \left(\sum_{k=1}^{N} z_k \mathbb{E}u_{ki} - x_i\right)^2 \end{array} \right] \end{aligned}$$

- The dartboard model implies $\mathbb{E}u_{ki} = x_i$, $Var\left(u_{ki}\right) = x_i\left(1 - x_i\right)$, and $Cov\left(u_{ki}, u_{li}\right) = \gamma x_i + \left(1 - \gamma\right) x_i^2 - x_i^2$
- By definition $\sum_{k=1}^{N} z_k = 1$, $\sum_{k=1}^{N} z_k^2 = H$, and $\sum_{k=1}^{N} \sum_{l \neq k} z_k z_l = 1 - H$

The Ellison and Glaeser (1997) Index

- The dartboard model yields

$$\mathbb{E}G = \left(1 - \sum_{i=1}^{M} x_i^2\right)\left[\gamma + (1-\gamma) H\right]$$

- Unbiased estimator

$$\gamma = \frac{G / \left(1 - \sum_{i=1}^{M} x_i^2\right) - H}{1 - H}$$

1. Herfindahl index of geographic concentration $\sum_{i=1}^{M} s_i^2$
2. Raw concentration index, controlling for overall spatial concentration

$$\tilde{G} \equiv \frac{\sum_{i=1}^{M} (s_i - x_i)^2}{1 - \sum_{i=1}^{M} x_i^2}$$

3. Ellison–Glaeser index, controlling for industry concentration too

$$\gamma \equiv \frac{\tilde{G} - H}{1 - H}$$

Microfoundation: A Random Location Model

- N plants sequentially choose among M potential locations
- The k-th plant has a share z_k of industry employment
  - Control for exogenous industrial concentration
- Plant k chooses location $v_k = i$ to maximize profits

$$\log \pi_{ki} = \log \bar{\pi}_i + g_i \left(v_1, \ldots, v_{k-1} \right) + \varepsilon_{ki}$$

- Industry-specific natural advantages $\bar{\pi}_i$
- Localization economies $g_i \left(\ldots \right)$
  - The model works with forward-looking firms: $\mathbb{E} g_1 \left(v_1, \ldots, v_N \right)$
- Idiosyncratic plant–location match ε_{ki}

First-Nature Location Patterns

- ε_{ki} are Weibull random variables independent of each other and of $\bar{\pi}_i$
- Suppose there are no spillovers: $g_i \equiv 0$ for all i
- Then given realizations $\bar{\pi}_i$ this is a standard logit model
- Firm's locations are i.i.d. with

$$\Pr\left\{v_k = i \middle| \bar{\pi}_1, ..., \bar{\pi}_M\right\} = \frac{\bar{\pi}_i}{\sum_{j=1}^{M} \bar{\pi}_j}$$

- The model is required to fit the aggregate distribution of activity

$$\mathbb{E}\frac{\bar{\pi}_i}{\sum_{j=1}^{M} \bar{\pi}_j} = x_i$$

- x_i is the share of aggregate employment in region i
  - Control for economy-wide concentration

Unobserved Natural Advantages

- A single parameter captures heterogeneity in natural advantages

$$\exists \gamma^{na} \in [0,1] : Var\left(\frac{\bar{\pi}_i}{\sum_{j=1}^{M} \bar{\pi}_j}\right) = \gamma^{na} x_i (1 - x_i)$$

- If $\xi \in [0,1]$ and $\mathbb{E}\xi = x$, then $Var(\xi) \in [0, x(1-x)]$
- The higher γ^{na}, the more first nature determines location
- The only observable predictor of $\bar{\pi}_i$ is x_i
- Ellison and Glaeser (1999) try to estimate other determinants

Second-Nature Forces

- Spillovers, regardless of their source, satisfy

$$g_i = -\infty \sum_{l \neq k} e_{kl} \left(1 - u_{li}\right)$$

- u_{li} is an indicator for firm l's choice of region i ($v_l = i$)
- e_{kl} is a Bernoulli random variable capturing spillovers between k and l

$$\mathbb{E} e_{kl} = \Pr\left\{e_{kl} = 1\right\} = \gamma^s$$

- Spillovers are symmetric and transitive
  - The ordering of firms doesn't matter
  - Backward- and forward-looking behavior yield the same equilibrium

Back to the Dartboard

- Natural advantages
  - A randomly thrown dart hits region i with probability p_i
  - p_i is a random variable with $\mathbb{E}p_i = x_i$ and $Var\left(p_i\right) = \gamma^{na} x_i \left(1 - x_i\right)$
- Spillovers
  - A dart follows its immediate predecessor with probability γ^s
  - The underlying logit model microfounds this behavior
- The microfounded model is identical to the dartboard model for

$$\gamma = \gamma^s + \gamma^{na} - \gamma^s \gamma^{na}$$

- It is *impossible* to identify γ^s and γ^{na} separately

Most Localized Industries

Four-Digit Industry		H	G	γ
		15 Most Localized Industries		
2371	Fur goods	.007	.60	.63
2084	Wines, brandy, brandy spirits	.041	.48	.48
2252	Hosiery not elsewhere classified	.008	.42	.44
3533	Oil and gas field machinery	.015	.42	.43
2251	Women's hosiery	.028	.40	.40
2273	Carpets and rugs	.013	.37	.38
2429	Special product sawmills not elsewhere classified	.009	.36	.37
3961	Costume jewelry	.017	.32	.32
2895	Carbon black	.054	.32	.30
3915	Jewelers' materials, lapidary	.025	.30	.30
2874	Phosphatic fertilizers	.066	.32	.29
2061	Raw cane sugar	.038	.30	.29
2281	Yarn mills, except wool	.005	.27	.28
2034	Dehydrated fruits, vegetables, soups	.030	.29	.28
3761	Guided missiles, space vehicles	.046	.27	.25

Least Localized Industries

		15 Least Localized Industries		
3021	Rubber and plastics footwear	.06	.05	−.013
2032	Canned specialties	.03	.02	−.012
2082	Malt beverages	.04	.03	−.010
3635	Household vacuum cleaners	.18	.17	−.009
3652	Prerecorded records and tapes	.04	.03	−.008
3482	Small-arms ammunition	.18	.17	−.004
3324	Steel investment foundries	.04	.04	−.003
3534	Elevators and moving stairways	.03	.03	−.001
2052	Cookies and crackers	.03	.03	−.0009
2098	Macaroni and spaghetti	.03	.03	−.0008
3262	Vitreous china table, kitchenware	.13	.12	−.0006
2035	Pickles, sauces, salad dressings	.01	.01	−.0003
3821	Laboratory apparatus and furniture	.02	.02	−.0002
2062	Cane sugar refining	.11	.10	.0002
3433	Heating equipment except electric	.01	.01	.0002

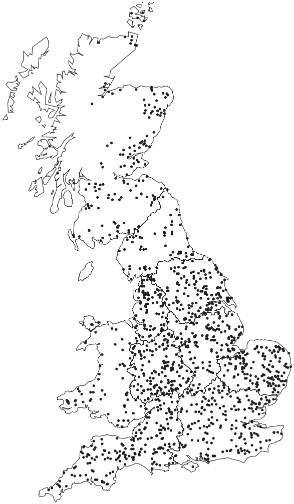
Micro-Geographic Data

- Duranton and Overman (2005) have the exact location of each plant
  - British postcodes are extremely detailed, often one per property

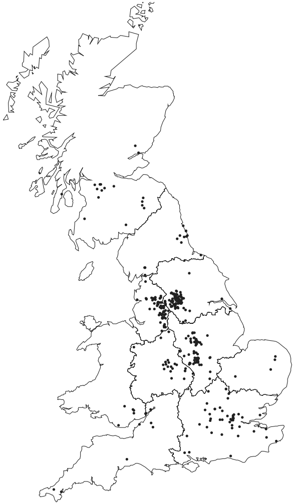
1. Consider the distribution of pairwise distances between plants in an industry
2. Compare it with a counterfactual randomly distributed industry
   - Same number of plants as the actual industry
   - Randomly drawn from the population of all plants, regardless of industry

- Avoids the modifiable areal unit problem
- Allows to test deviation from counterfactual
  - Measure of statistical significance

Extremes of Localization and Dispersion



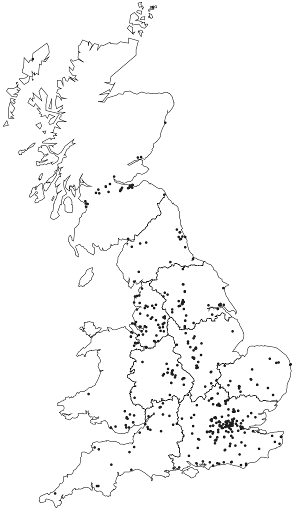
(c) Other Agricultural and Forestry Machinery (SIC2932)



(d) Machinery for Textile, Apparel and Leather Production (SIC2954)

Ambiguous Cases

(a) Basic Pharmaceuticals (SIC2441)



(b) Pharmaceutical Preparations (SIC2442)

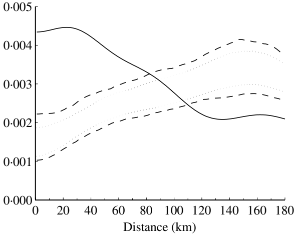
Duranton and Overman's (2005) Methodology

For an industry with N plants

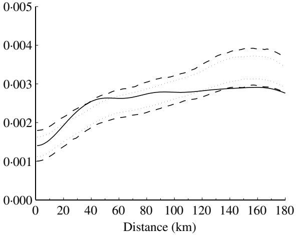
1. Calculate all $N(N-1)/2$ bilateral distances
2. Estimate non-parametrically the distribution of bilateral distances
    - Gaussian kernel estimator
    - Measured Euclidean distance as a proxy for true physical distance
3. Construct a counterfactual
    1. Random sample of N draws from the population of plants in all sectors
    2. Calculate all $N(N-1)/2$ bilateral distances
    3. Estimate non-parametrically the distribution of bilateral distances

    - Repeat the three steps of the simulation $1,000$ times
4. Calculate lower and upper confidence intervals
    - K-density above the upper band $=$ localization
    - K-density below the lower band $=$ dispersion

Four Illustrative Industries



(a) Basic Pharmaceuticals (SIC2441)



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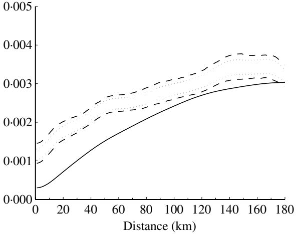

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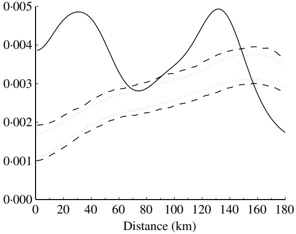


(d) Machinery for Textile, Apparel and Leather Production (SIC2954)

Localization of British Manufacturing

- 52% of manufacturing industries are localized
  - Their concentration is more than random, at a 5% confidence level
  - A more demanding index than Ellison and Glaeser's, which reports 94%
  - 24% of industries show dispersion at the 5% confidence level
- Localization mostly takes places at small scales
  - Distances below 50 km for four-digit industries
- Similar industries tend to have similar localization patterns
  - Four-digit industries within three-digit sectors
  - Some co-localization of related industries

Measuring Agglomeration Economies Through Localization

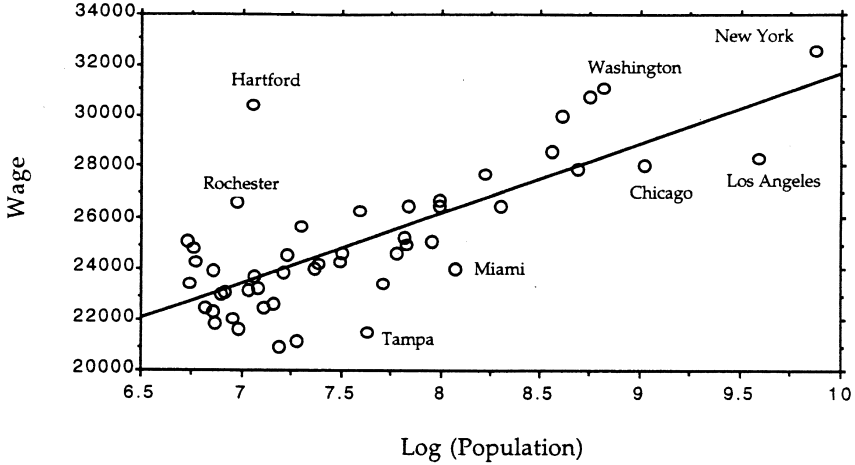
- Careful data analysis
  - Establishing facts is valued in the field
  - Methodological contributions
- Most industries are more concentrated than the economy as a whole

No evidence on the causes of localization

1. Industry-specific natural advantages are a perfect confound for localization economies
   - Ellison and Glaeser (1999) won't convince the identification police
2. Economy-wide effects are filtered out
   - Common natural advantages are probably present
   - Urbanization economies are probably present too

- We didn't really learn anything about our main question

Wages and City Population in the U.S.



Measuring Agglomeration Economies Through Wages

- Wages are higher in larger cities
  - True in history and around the world
- Direct evidence of agglomeration economies and their magnitude

Why do firms stay in cities with high wages?

1. Ability bias: more productive workers live in cities
2. Agglomeration economies: cities make workers more productive

- Endogenous sorting is the problem with this approach

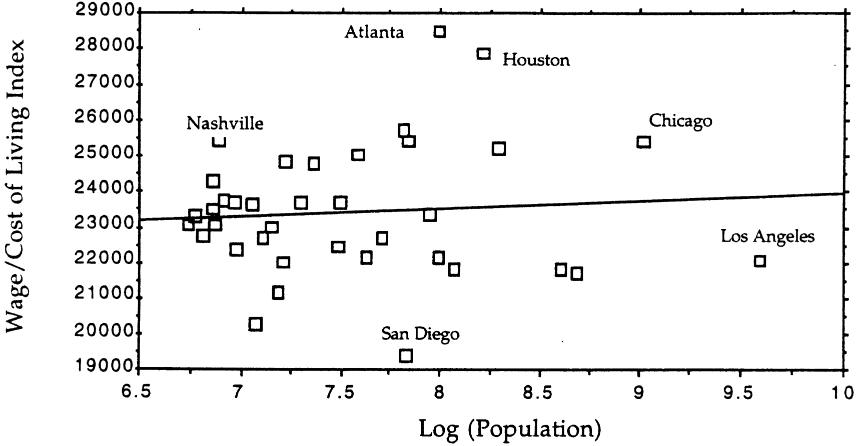
Worker Preferences

- Theoretical perspective on endogenous sorting
- Supply side of the urban labor market

1. Ability bias: higher real wages in larger cities
   - More productive workers earn a skill premium
2. Agglomeration economies: invariant real wages
   - More productive cities have higher rents

- Real wages are not higher in larger cities
  - Housing is more expensive in larger cities
- But what about consumption amenities?

Wages Adjusted by Cost of Living



Controlling for Observables: Glaeser and Maré (2001)

- Individual data for earnings and worker characteristics
- Mincerian wage regression controlling for
  - Education: level or years
  - Experience: years worked
- Additional worker characteristics:
  - Ethnicity: strongly correlated with earnings
  - Occupation: average education level associated with a job
  - Tenure: worker-specific labor-market outcome
  - Cognitive ability: AFQT score
- Individual fixed effects in panel data
  - But what is the timing of the urban premium?
- The search for a convincing instrument is on

Individual-Level OLS Wage Regressions

	1990 Census Basic Wage Equation (1)	1990 Census Basic Wage Equation with Occupational Education (2)	PSID Basic Wage Equation (3)	PSID Basic Wage Equation with Labor Market Variables (4)	NLSY Basic Wage Equation (5)	NLSY Basic Wage Equation with Occupational Education (6)	NLSY Basic Wage Equation (7)	NLSY Fixed-Effects Estimator (8)	PSID Individual Fixed-Effects Estimator (9)
Dense metropolitan premium	.287 (.00)	.269* (.00)	.282* (.01)	.259* (.01)	.249* (.01)	.245* (.01)	.243* (.01)	.109* (.01)	.045* (.01)
Nondense metropolitan premium	.191* (.00)	.179* (.00)	.148* (.01)	.133* (.01)	.153* (.01)	.147* (.01)	.141* (.01)	.070* (.01)	.026* (.01)
Experience dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Education dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nonwhite	−.169* (.00)	−.156* (.00)	−.193*(.01)	−.173* (.01)	−.159* (.01)	−.137* (.01)	−.087* (.01)	N.A.	N.A.
Average education in (one-digit) occupational group		.055* (.00)		.039* (.00)		.034* (.00)	.027* (.00)	.009* (.00)	.016* (.00)
Tenure				.015* (.00)		.001* (.00)	.001* (.00)	.000* (.00)	.010* (.00)
AFQT							.002* (.00)	N.A.	
Time dummies	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2 (%)	20.4	21.6	30.2	34.7	29.4	33.0	33.7	28.4	20.6
N	332,609	332,609	39,485	39,485	40,194	40,194	40,194	40,194	39,485

NOTE.—Numbers in parentheses are standard errors. PSID = Panel Study of Income Dynamics; NLSY = National Longitudinal Study of Youth; AFQT = Armed Forces Qualification Test.

* Significant at 1% level.

The Timing of the Urban Wage Premium

1. Usual view: wage level effect
   - Firms are more productive in cities
   - Workers receive immediate wage gains when they move to a dense city
   - They suffer immediate losses when they leave
2. Alternative view: wage growth effect (Glaeser 1999)
   - Cities facilitate human capital accumulation
   - Wage gains accrue over time as a worker lives in a dense city
   - Workers keep most of the accrued premium when they leave

- Dummies for each worker's migration path
  - Some immediate gains for young rural-to-urban migrants
  - The urban wage premium grows over time
  - Little losses for urban-to-rural migrants

Measuring Agglomeration Economies Through Productivity

- The most direct approach
  - Measure productivity from output, then relate it to density

Endogeneity problems

- Reverse causality
  1. Natural advantages make a region more productive
  2. Greater productivity attracts workers and firms
  3. Density rises until congestion costs compensate natural advantages
- Output per worker may not be the appropriate measure
  - Capital could be used more intensively in denser cities
  - Switch to total factor productivity: more difficult to measure
- You can always worry about endogenous sorting too

Productivity and Density: Ciccone and Hall (1996)

- Macroeconomic focus on increasing returns
- Theoretical models: externalities or non-tradable intermediates
  - Simplified version in the *Palgrave Dictionary* (Ciccone 2008)
- Very limited and casual discussion of spatial equilibrium
- Little attention to omitted worker characteristics
- Main contribution: IV for density by state in 1988
  1. Presence of a railroad in 1860
  2. State population in 1850
  3. State population density in 1880
  4. Distance from eastern seaboard

Identification by Historical Instruments

$$\begin{array}{ccc} \textit{density}_{1988} & \leftrightarrows & \textit{productivity}_{1988} \\ \uparrow & \not\nearrow & \\ \textit{density}_{1880} & & \end{array}$$

Identification by Historical Instruments

$$
\begin{array}{ccccccc}
\textit{worker prefs}_{1988} & \longrightarrow & \textit{density}_{1988} & \leftrightarrows & \textit{productivity}_{1988} & \longleftarrow & \textit{prod adv}_{1988} \\
\uparrow & & & \not\nearrow & \not\nwarrow & & \not\nwarrow \\
\textit{worker prefs}_{1880} & \longrightarrow & \textit{density}_{1880} & \leftrightarrows & \textit{productivity}_{1880} & \longleftarrow & \textit{prod adv}_{1880}
\end{array}
$$

- No persistent productivity advantages
- Persistent consumption amenities only

- If the null hypothesis is rejected, persistent clusters

Identification by Historical Instruments

$$
\begin{array}{ccccccc}
\textit{worker prefs}_{1988} & \longrightarrow & \textit{density}_{1988} & \leftrightarrows & \textit{productivity}_{1988} & \longleftarrow & \textit{prod adv}_{1988} \\
\uparrow & & & \not\nearrow & \not\nwarrow & & \not\nwarrow \\
\textit{worker prefs}_{1880} & \longrightarrow & \textit{density}_{1880} & \leftrightarrows & \textit{productivity}_{1880} & \longleftarrow & \textit{prod adv}_{1880}
\end{array}
$$

- No persistent productivity advantages
- Persistent consumption amenities only

- If the null hypothesis is rejected, persistent clusters
  - But this isn't econometrically proper

Increasing Returns from Externalities

- Production function for firm f in county c

$$q_f = \left(n_f^\alpha k_f^\beta m_f^{1-\alpha-\beta}\right)^{1-\rho} \left(\frac{Q_c}{A_c}\right)^\lambda$$

  - Firm output q_f with n_f workers, capital k_f, m_f intermediates
  - Aggregate county output Q_c and total acreage A_c
- Fixed amount of land per firm: $\rho < 1$ would capture congestion
- Agglomeration effects: $\lambda > 0$ would capture production externalities

Competitive Firms

- Derived demand for capital at rental price R

$$k_f = \beta (1-\rho) q_f / R$$

- Derived demand for intermediates at a unit price

$$m_f = (1-\alpha-\beta)(1-\rho) q_f$$

- Firm output

$$q_f = \kappa_q n_f^{\frac{\alpha(1-\rho)}{1-(1-\alpha)(1-\rho)}} \left(\frac{Q_c}{A_c}\right)^{\frac{\lambda}{1-(1-\alpha)(1-\rho)}}$$

- Value added

$$\begin{aligned} y_f &\equiv q_f - m_f = [1-(1-\alpha-\beta)(1-\rho)] q_f \\ &= \kappa_y n_f^{\frac{\alpha(1-\rho)}{1-(1-\alpha)(1-\rho)}} \left(\frac{Y_c}{A_c}\right)^{\frac{\lambda}{1-(1-\alpha)(1-\rho)}} \end{aligned}$$

  - κ_q and κ_y are unimportant functions of constant parameters

Increasing Returns to Density

- Assume that labor is uniformly distributed across a county

$$n_f = \frac{N_c}{A_c} \text{ for all firms } f \text{ in county } c$$

  - Debatable hypothesis that the paper does not defend

- County-level production function

$$\frac{Y_c}{A_c} = \kappa_Y \left(\frac{N_c}{A_c} \right)^{1+\theta}$$

- Increasing returns to density if

$$\theta \equiv \frac{\lambda - \rho}{\alpha (1 - \rho) - \lambda + \rho} > 0$$

  - Strong externalities λ, little congestion ρ

State-Level Regression

- Value added is observed at the state, not the county level
- Output per worker by state

$$\frac{Y_s}{N_s} = \kappa_Y \sum_{c \in s} \frac{N_c}{N_s} \left(\frac{N_c}{A_c} \right)^{\theta}$$

- Nonlinear estimation

$$\log \frac{Y_s}{N_s} = \beta_0 + \log \left[\sum_{c \in s} \frac{N_c}{N_s} \left(\frac{N_c}{A_c} \right)^{\theta} \right] + \varepsilon_s$$

- Doubling employment density increases productivity by almost 6%
  - A range of 3 to 8% is consistent with other studies
- Instrumenting for reverse causality hardly makes a difference
  - The broader literature confirms reverse causality is a minor problem

Productivity Benefits of Density

TABLE 1—ESTIMATION RESULTS

Instrument	Density elasticity, θ (standard error)	Education elasticity, η (standard error)	R^2
None (NLLS)	1.052	0.410	0.551
	(0.008)	(0.396)	
Eastern seaboard	1.055	0.460	0.548
	(0.017)	(0.51)	
Railroad in 1860	1.061	0.330	0.537
	(0.011)	(0.450)	
Population in 1850	1.060	0.350	0.539
	(0.015)	(0.510)	
Population density	1.051	0.530	0.549
in 1880	(0.019)	(0.550)	
All	1.06	0.060	0.536
	(0.01)	(0.82)	

Notes: The equation estimated is (24). The data are value added for 46 states and Washington DC. For the 46 states we have used data on employment and average years of education at the county level.

Density or Size?

- Add another externality to the model

$$q_f = \left(n_f^{\alpha} k_f^{\beta} m_f^{1-\alpha-\beta}\right)^{1-\rho} \left(\frac{Q_c}{A_c}\right)^{\lambda} Q_c^{\nu}$$

- Estimates suggest that density matters more than total employment

TABLE 6—ESTIMATION RESULTS WITH SIZE EFFECTS

Instrument	County density elasticity, θ (standard error)	Education elasticity, η (standard error)	County size elasticity, σ (standard error)
None (NLLS)	1.035 (0.013)	0.259 (0.398)	1.029 (0.019)
All	1.046 (0.023)	0.140 (0.82)	1.026 (0.039)

Notes: The equation estimated is (39). The data used is value added for 46 states and Washington, DC. For the 46 states we have used data on employment and education at the county level.

Greenstone, Hornbeck, and Moretti (2010)

- The opening of new plants increases employment in an area
- Does the productivity of existing plants increase as a result?

Identification problem

- New plants choose their location to maximize profits
- Places without new plants are not a valid control group
  - Their productivity cannot be used as a counterfactual
- Fixed effects are not sufficient either
  - The location decision is forward looking
  - New firms come in anticipation of exogenously rising productivity

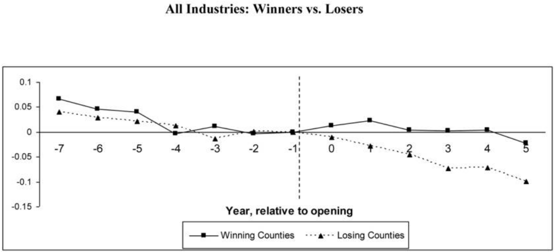
"Million Dollar Plants"

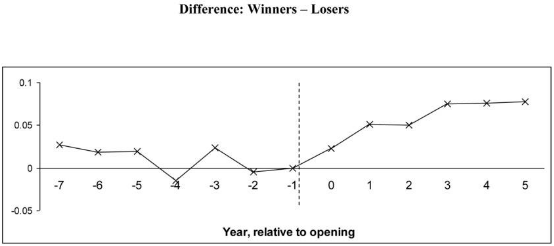
- Regular feature in the corporate real estate journal *Site Selection*
- Stories about the location choice of large new plants
- Gradual narrowing down of potential counties to 2 or 3 finalists
- The 1 or 2 losers in the shortlist provide a control group
  - Almost as attractive as the winning county
  - Yet, they did not receive the treatment
- Plant-level regression
  - Estimate TFP by controlling for factor employment
- Control for trends, pre- and post-opening
  - Establish similarity of treatment and control group before opening
  - Check for structural break in trends as well as levels

Practical Implementation

- 82 featured articles
- Check in Census data if the plant was really opened and where
- Collect productivity data for existing firms in the winning county
  - 8 years before the opening to 5 years afterwards
  - Only use incumbent firms that existed all 8 previous years
- Do the same for control group of losing counties
- 47 new openings of manufacturing firms with sufficient data
- Average output of new plants 5 years after opening: $450 million
  - Around 9% of the whole county's output before the opening

Productivity of Incumbent Plants





Changes in Productivity Following an MDP Opening

	All Counties: MDP Winners − MDP Losers		MDP Counties: MDP Winners − MDP Losers		All Counties: Random Winners
	(1)	(2)	(3)	(4)	(5)
	A. Model 1				
Mean shift	.0442*	.0435*	.0524**	.0477**	− 0.0496***
	(.0233)	(.0235)	(.0225)	(.0231)	(.0174)
				[$170 m]	
R^2	.9811	.9812	.9812	.9860	~0.98
Observations (plant by year)	418,064	418,064	50,842	28,732	~400,000
	B. Model 2				
Effect after 5 years	.1301**	.1324**	.1355***	.1203**	−.0296
	(.0533)	(.0529)	(.0477)	(.0517)	(.0434)
				[$429 m]	
Level change	.0277	.0251	.0255	.0290	.0073
	(.0241)	(.0221)	(.0186)	(.0210)	(.0223)
Trend break	.0171*	.0179**	.0183**	.0152*	− 0.0062
	(.0091)	(.0088)	(.0078)	(.0079)	(.0063)
Pre-trend	−.0057	−.0058	−.0048	−.0044	−.0048
	(.0046)	(.0046)	(.0046)	(.0044)	(.0040)
R^2	.9811	.9812	.9813	.9861	~.98
Observations (plant by year)	418,064	418,064	50,842	28,732	~400,000
Plant and industry by year fixed effects	Yes	Yes	Yes	Yes	Yes
Case fixed effects	No	Yes	Yes	Yes	NA
Years included	All	All	All	$-7 \leq \tau \leq 5$	All

Who Benefits from Million Dollar Plants?

- Highly heterogeneous productivity gains
  - On average $+0.6\sigma$ or $+\$430$ million
  - Nil or even negative in some cases
- Spillovers through labor markets
  - Larger for industries that share worker flows with the MDP industry
- Spillovers through technological linkages
  - Measured by patent citations and usage of R&D spending from a sector
- Little evidence of spillovers through input–output linkages
- New firms enter
- Local wages increase, controlling for worker quality

Transport Costs and Agglomeration Economies

The oldest centripetal force

1. Economic history: waterways and U.S. cities until 1900
2. History of economic thought: Krugman in the 1990s

Sources of agglomeration economies

1. Increasing returns at the firm level
2. Transport costs

Sources of analytical tractability

1. Monopolistic competition with CES demand
2. Iceberg transport costs

The Consumer's Problem

- Cobb-Douglas utility

$$U = \mu \log \frac{C}{\mu} + (1-\mu) \log \frac{A}{1-\mu}$$

  - Constant budget share $\mu \in (0, 1]$
- A denotes consumption of a homogeneous good
- C denotes consumption of the Dixit-Stiglitz aggregate

$$C = \left(\int_0^n c_i^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}$$

  - Constant elasticity of substitution $\sigma > 1$
  - n available varieties of differentiated products
- Budget constraint

$$p^A A + \int_0^n p_i c_i di = Y$$

Isoelastic Demand

- Expenditure-minimizing differentiated bundle

$$\min \int_0^n p_i c_i di \text{ s.t. } C = \left(\int_0^n c_i^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}$$

- First-order condition

$$\frac{c_i}{c_j} = \left(\frac{p_i}{p_j} \right)^{-\sigma} \text{ for all } i, j \in [0, n]$$

- Compensated demand function

$$c_j = p_j^{-\sigma} C \left(\int_0^n p_i^{1-\sigma} di \right)^{\frac{\sigma}{1-\sigma}} = \left(\frac{p_j}{P} \right)^{-\sigma} C$$

- Price index

$$P \equiv \left(\int_0^n p_i^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$$

Constant Budget Shares

- Demand for the homogeneous good

$$A = (1 - \mu) \frac{Y}{p^A}$$

- Demand for the Dixit-Stiglitz aggregate

$$C = \mu \frac{Y}{P}$$

- Demand for each differentiated variety

$$c_j = \mu p_j^{-\sigma} P^{\sigma - 1} Y$$

- Indirect utility

$$U = \log Y - \mu \log P - (1 - \mu) \log p^A$$

Iceberg Transport Costs

- Region r produces measure n_r of varieties
- Suppose each variety produced in region r has f.o.b. price p_r
- For each unit shipped from r to s a fraction $\tau_{rs} < 1$ is delivered
- C.i.f. price $p_{rs} = p_r / \tau_{rs}$
- Price index in region s

$$P_s = \left[\sum_{r=1}^{R} n_r \left(\frac{p_r}{\tau_{rs}} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$$

  - Or the equivalent with a continuum of regions, which can be useful

- F.o.b. demand for each variety produced in region r

$$q_r = \mu p_r^{-\sigma} \sum_{s=1}^{R} (\tau_{rs} P_s)^{\sigma-1} Y_s$$

Monopolistic Competition

- Differentiated goods are produced with increasing returns to scale
- Labor requirement

$$l_j = f + \beta q_j = f + \frac{\sigma - 1}{\sigma} q_j$$

  - fixed input f
  - unit labor requirement β
  - choose units for output such that $\beta = (\sigma - 1)/\sigma$

- Profit maximization for each firm in region r with wage w_r

$$\max (p_r - \beta w_r) q_r \Rightarrow \max_{p_r} (p_r - \beta w_r) p_r^{-\sigma}$$

- Constant mark up

$$p_r = \beta \frac{\sigma}{\sigma - 1} w_r = w_r$$

Free Entry

- Profits

$$\pi_r = w_r \left(\frac{\beta}{\sigma - 1} q_r - f \right)$$

- Zero-profit firm output in all regions

$$q = \frac{\sigma - 1}{\beta} f = \sigma f$$

- Zero-profit firm employment in all regions

$$l = \sigma f$$

- Employment N_r determines variety

$$n_r = \frac{N_r}{\sigma f}$$

but not firm size nor mark ups

Wages and Backward Linkages

- Zero-profit wage in region r

$$w_r = \left[\frac{\mu}{\sigma f} \sum_{s=1}^{R} (\tau_{rs} P_s)^{\sigma - 1} Y_s \right]^{\frac{1}{\sigma}}$$

Backward linkages

1. Increasing in market size: $\partial w_r / \partial Y_s > 0$
2. Increasing in access to customers: $\partial w_r / \partial \tau_{rs} > 0$
3. Decreasing with competition: $\partial w_r / \partial P_s > 0$ and $\partial P_s / \partial n < 0$

Prices and Forward Linkages

- Price index in region r

$$P_r = \left[\frac{1}{\sigma f} \sum_{s=1}^{R} N_s \left(\frac{w_s}{\tau_{sr}} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$$

Forward linkages

1. Increasing in input supply: $\partial P_r / \partial N_s < 0$
2. Increasing in access to suppliers: $\partial P_r / \partial \tau_{sr} < 0$
3. Decreasing with input prices: $\partial P_r / \partial w_s > 0$

Centrifugal Forces

Krugman's (1991) original assumptions

1. There is a homogeneous good A: $\mu < 1$
2. A is a costlessly traded numeraire: $p^A = 1$
3. A is produced with constant returns under perfect competition
4. A is produced using a specific factor L
5. L is immobile and each region is endowed with L_r

- L_r generates an immobile demand for differentiated goods
- Centrifugal force from forward linkages

Later New Economic Geography models have also used commuting costs as the agglomeration diseconomy

Spatial Equilibrium

A system or $1 + 4R$ equations in as many unknowns $(N_r, w_r, P_r, Y_r, \omega)$

- Fixed aggregate amount of labor $N = \sum_{r=1}^{R} N_r$
- Aggregate income
$$Y_r = L_r + w_r N_r$$
- Nominal wage
$$w_r = \left[\frac{\mu}{\sigma f} \sum_{s=1}^{R} (\tau_{rs} P_s)^{\sigma-1} Y_s\right]^{\frac{1}{\sigma}}$$
- Price index
$$P_r = \left[\frac{1}{\sigma f} \sum_{s=1}^{R} N_s \left(\frac{w_s}{\tau_{sr}}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$
- Real wage
$$\omega = w_r P_r^{-\mu}$$

Two Symmetric Regions

1. The immobile factor is uniformly distributed: $L_1 = L_2 = L/2$
2. Transport costs are symmetric: $\tau_{12} = \tau_{21} = \tau$

Given N_1, w_1 and w_2 we have

1. Population
$$N_2 = N - N_1$$
2. Aggregate income
$$\begin{cases} Y_1 = L/2 + w_1 N_1 \\ Y_2 = L/2 + w_2 N_2 \end{cases}$$
3. Price indices
$$\begin{cases} P_1 = \left\{ \frac{1}{\sigma f} \left[N_1 w_1^{1-\sigma} + (N - N_1) \left(\frac{w_2}{\tau}\right)^{1-\sigma} \right] \right\}^{\frac{1}{1-\sigma}} \\ P_2 = \left\{ \frac{1}{\sigma f} \left[N_1 \left(\frac{w_1}{\tau}\right)^{1-\sigma} + (N - N_1)\, w_2^{1-\sigma} \right] \right\}^{\frac{1}{1-\sigma}} \end{cases}$$

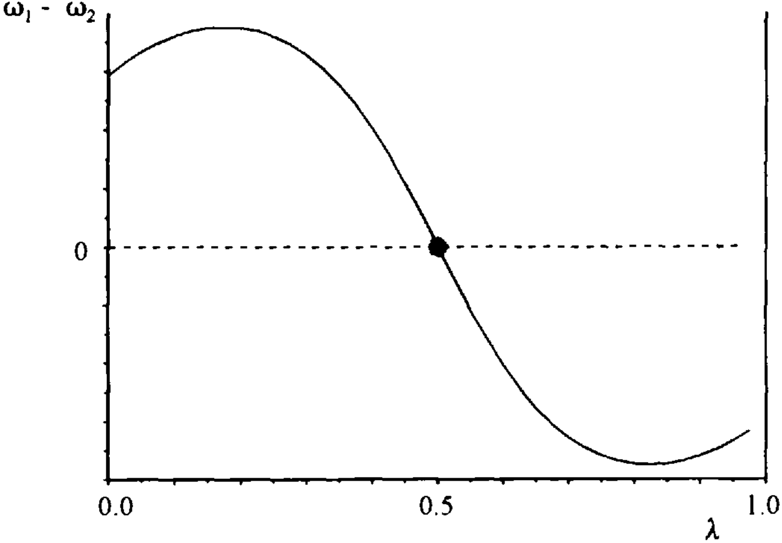
Numerical Solution

- Given N_1, wages solve

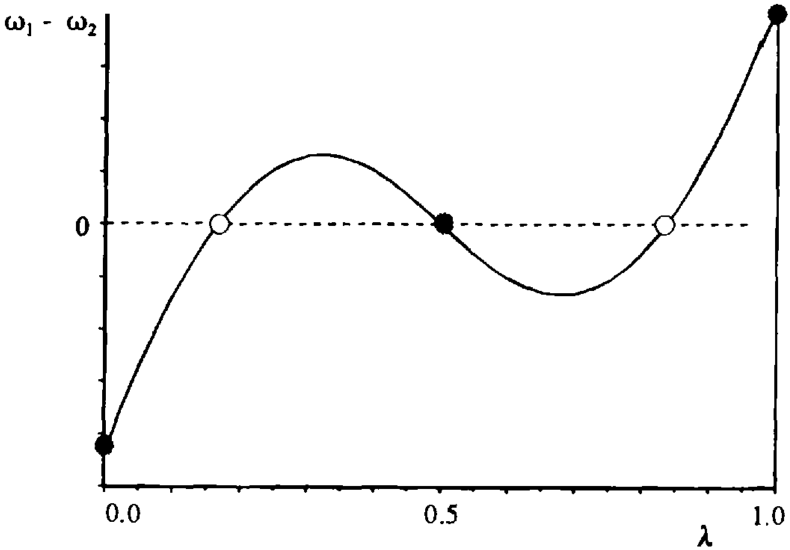
$$\begin{cases} \frac{1}{\mu} w_1^{\sigma} = \frac{L/2+N_1 w_1}{N_1 w_1^{1-\sigma}+\tau^{\sigma-1}(N-N_1)w_2^{1-\sigma}} + \frac{\tau^{\sigma-1}[L/2+(N-N_1)w_2]}{\tau^{\sigma-1}N_1 w_1^{1-\sigma}+(N-N_1)w_2^{1-\sigma}} \\ \frac{1}{\mu} w_2^{\sigma} = \frac{\tau^{\sigma-1}(L/2+N_1 w_1)}{N_1 w_1^{1-\sigma}+\tau^{\sigma-1}(N-N_1)w_2^{1-\sigma}} + \frac{L/2+(N-N_1)w_2}{\tau^{\sigma-1}N_1 w_1^{1-\sigma}+(N-N_1)w_2^{1-\sigma}} \end{cases}$$

- This system can be solved numerically for nominal wages $w_r(N_1)$
- These imply prices $P_r(N_1)$ and real wages $\omega_r(N_1)$
- Plotting $\omega_1(N_1) - \omega_2(N_2)$ shows graphically
  1. All equilibria, which are the roots of this function
  2. Equilibrium stability according to a heuristic definition
- An equilibrium is "stable" if a city's appeal decreases with a marginal increase in its size

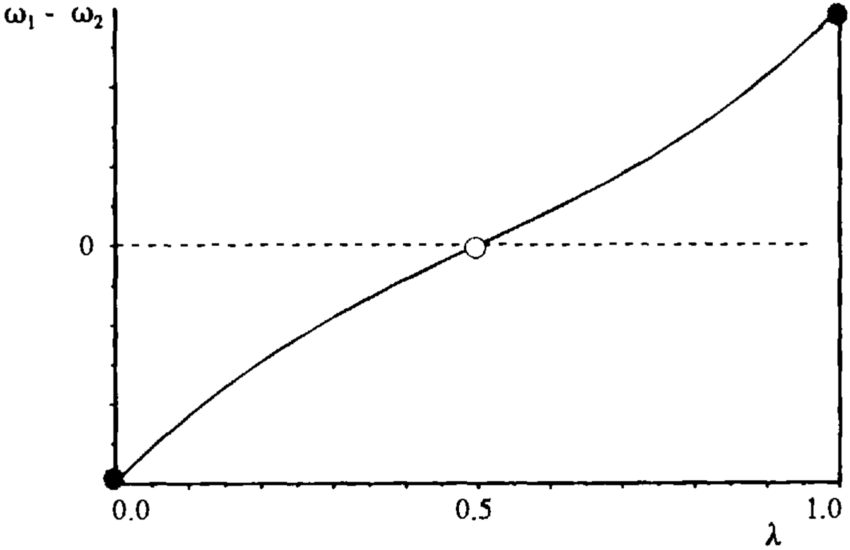
High Transport Costs



Intermediate Transport Costs



Low Transport Costs



Symmetric Equilibrium

- Suppose that $N_1 = N_2 = N/2$
- Nominal wages

$$w_1 = w_2 = \frac{\mu}{1-\mu}\frac{L}{N}$$

- Price indices

$$P_1 = P_2 = \left[\frac{N}{\sigma f}\left(\frac{1+\tau^{\sigma-1}}{2}\right)\right]^{\frac{1}{1-\sigma}} w_r$$

- Real wages

$$\omega_1 = \omega_2 = \left[\frac{N}{\sigma f}\left(\frac{1+\tau^{\sigma-1}}{2}\right)\right]^{\frac{\mu}{\sigma-1}} w_r^{1-\mu}$$

- Aggregate incomes

$$Y_1 = Y_2 = \frac{L}{2(1-\mu)}$$

Stability of the Symmetric Equilibrium

- The symmetric equilibrium always exists, but is it stable?
- Take half of the original system

$$\begin{cases} Y_1 = \frac{L}{2} + w_1 N_1 \\ \frac{\sigma f}{\mu} w_1^{\sigma} = P_1^{\sigma-1} Y_1 + (\tau P_2)^{\sigma-1} Y_2 \\ \sigma f P_1^{1-\sigma} = N_1 w_1^{1-\sigma} + N_2 \left(\frac{w_2}{\tau}\right)^{1-\sigma} \\ \omega_1 = w_1 P_1^{-\mu} \end{cases}$$

- Around the symmetric equilibrium, $dX_1 = -dX_2$ for all X

$$\begin{cases} d \log Y_1 = \mu \left(d \log w_1 + d \log N_1\right) \\ \sigma d \log w_1 = t \left[(\sigma - 1) d \log P_1 + d \log Y_1\right] \\ d \log P_1 = t \left(d \log w_1 - \frac{1}{\sigma-1} d \log N_1\right) \\ d \log \omega_1 = d \log w_1 - \mu d \log P_1 \end{cases}$$

for trade barriers

$$t \equiv \frac{1 - \tau^{\sigma-1}}{1 + \tau^{\sigma-1}} \in [0, 1]$$

Log-Linearization

Around the symmetric equilibrium

- Income

$$\frac{d\log Y_1}{d\log N_1} = \frac{\mu\sigma\left(1-t^2\right)}{\sigma-\mu t-(\sigma-1)\,t^2} \geq 0$$

- Price index

$$\frac{d\log P_1}{d\log N_1} = -\frac{\sigma\left(1-\mu t\right)t}{(\sigma-1)\left[\sigma-\mu t-(\sigma-1)\,t^2\right]} \leq 0$$

- Nominal wage

$$\frac{d\log w_1}{d\log N_1} = \frac{(\mu-t)\,t}{\sigma-\mu t-(\sigma-1)\,t^2}$$

- Real wage

$$\frac{d\log \omega_1}{d\log N_1} = \frac{\left[\mu\left(2\sigma-1\right)-\left(\mu^2\sigma+\sigma-1\right)t\right]t}{(\sigma-1)\left[\sigma-\mu t-(\sigma-1)\,t^2\right]}$$

Break Point

- The symmetric equilibrium is stable if

$$t > \frac{\mu(2\sigma - 1)}{\mu^2\sigma + \sigma - 1} \Leftrightarrow \tau < \left[\frac{(1-\mu)(\sigma - 1 - \sigma\mu)}{(1+\mu)(\sigma - 1 + \sigma\mu)}\right]^{\frac{1}{\sigma-1}}$$

- This is impossible if increasing returns are too strong

$$\frac{\sigma - 1}{\sigma} < \mu$$

- If increasing returns are weak enough there is a break point $\tau_B > 0$
- Less stability when the share of varieties is greater: $\partial\tau_B/\partial\mu < 0$
  - The numeraire provides the centrifugal force
- More stability when varieties are more substitutable: $\partial\tau_B/\partial\sigma > 0$
  - Love of variety provides the centripetal force

Core-Periphery Equilibrium

- Suppose that $N_1 = N$
- Nominal wages

$$w_1 = \frac{\mu}{1-\mu}\frac{L}{N} \text{ and } w_2 = \left[\frac{1+\mu}{2}\tau^{\sigma-1} + \frac{1-\mu}{2}\tau^{1-\sigma}\right]^{\frac{1}{\sigma}} w_1$$

- Price indices

$$P_1 = \left(\frac{\sigma f}{N}\right)^{\frac{1}{\sigma-1}} w_1 \text{ and } P_2 = \frac{1}{\tau}P_1$$

- Real wages

$$\omega_1 = \left(\frac{N}{\sigma f}\right)^{\frac{\mu}{\sigma-1}} w_1^{1-\mu} \text{ and } \omega_2 = \tau^{\mu}\left[\frac{1+\mu}{2}\tau^{\sigma-1} + \frac{1-\mu}{2}\tau^{1-\sigma}\right]^{\frac{1}{\sigma}} \omega_1$$

Existence of the Core-Periphery Equilibrium

- The core-periphery equilibrium exists if

$$\frac{\omega_2}{\omega_1} = \tau^{\mu\sigma} \left[\frac{1+\mu}{2} \tau^{\sigma-1} + \frac{1-\mu}{2} \tau^{1-\sigma} \right] \leq 1$$

- The left-hand side is a function ν such that

$$\frac{\partial \nu}{\partial \tau} = \frac{\mu\sigma\nu}{\tau} + (\sigma - 1)\, \tau^{\mu\sigma-1} \left[\frac{1+\mu}{2} \tau^{\sigma-1} - \frac{1-\mu}{2} \tau^{1-\sigma} \right]$$

and at any stationary point

$$\frac{\partial \nu}{\partial \tau} = 0 \Rightarrow \frac{\partial^2 \nu}{\partial \tau^2} = (\sigma - 1 - \mu\sigma) \frac{(\sigma - 1 + \mu\sigma)\, \nu}{\tau^2}$$

- The equilibrium always exists for low transport costs

$$\lim_{\tau \to 1} \nu = 1 \text{ and } \lim_{\tau \to 1} \frac{\partial \nu}{\partial \tau} = \mu\, (2\sigma - 1) > 0$$

Sustain Point

- If increasing returns are too strong

$$\frac{\sigma - 1}{\sigma} < \mu$$

the core-periphery equilibrium is a "black hole"

$$\frac{\partial \nu}{\partial \tau} > 0 \text{ for all } \tau \in (0, 1) \text{ and } \lim_{\tau \to 0} \nu = 0$$

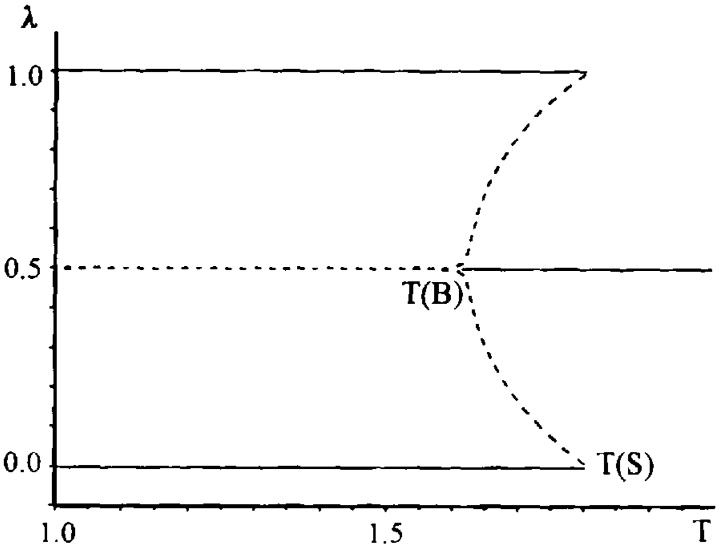
- If increasing returns are weak enough there is a sustain point $\tau_S > 0$

$$\lim_{\tau \to 0} \nu = \infty$$

- Analogous comparative statics for break and sustain points

$$\partial \tau_S / \partial \mu < 0 < \partial \tau_S / \partial \sigma$$

Bifurcation



Transport Costs and the Rise of U.S. Cities

- American cities grew on waterways before 1900
  - 8 on the Atlantic (Boston, Providence, New York, Jersey City, Newark, Philadelphia, Baltimore, Washington)
  - 5 on the Great Lakes (Milwaukee, Chicago, Detroit, Cleveland, Buffalo)
  - 3 on the Ohio (Louisville, Cincinnati and Pittsburgh)
  - 3 on the Mississippi (Minneapolis, St. Louis, New Orleans)
  - 1 on the Pacific (San Francisco)
- Railroads were built to complement waterways
- Manufacturing located in transportation hubs
  - Centralized to exploit economies of scale
  - Close to ports and rail yards for market access
- Smaller cities throughout the U.S. catering to diffuse agriculture

The Port of New York

- New York City takes off 1790–1860
  - Population: 33 to 814 thousand (117% to 300% of Philadelphia)
  - Exports: 13 to 145 million $ (108% to 853% of Boston)
- The best Atlantic harbour
  - Centrally located (vs. Boston, Charleston, New Orleans)
  - Deep water and close to the ocean (vs. Baltimore, Philadelphia)
  - Inland navigation on the Hudson and on the Erie Canal (1825)
- Complementary to shipping technology
  - Tonnage increases from $<$500 to $>$1500 tons
  - Specialized ships for hub and spoke network
  - Triangular trade with Europe and the South

Manufacturing Around the Port

- The main employer in NYC was manufacturing, not shipping
  - Already in the early XIX century and unlike in Boston
- Consistently three main industries

1. Sugar refining
   - Largest industry by value-added, 1810-1860
   - Large economies of scale
   - Best to refine after a long, humid shipment
2. Garment trade
   - Largest industry 1860-1970
3. Printing and publishing
   - Rises from third in 1860 to first in the 1970s
   - Originally reprinting British works obtained by sea

Chicago

- Chicago was built on the Chicago portage
  - Connection between the Mississippi system and the Great Lakes
  - Illinois and Michigan Canal (1848)
  - Then it becomes a railroad hub
- Chicago takes off 1860-1920
  - Population: 112,000 to 2,702,000 (14% to 48% of New York)
- The hub for the Great Plains
  - Slaughter and cure pork: the way to ship corn
  - Invention of the refrigerated rail car: the way to ship beef
  - Supplying agriculture: McCormick's harvester
  - Supplying farmers: mail order (Ward and Sears)
  - Trading in agricultural commodities and finance

Declining Incidence of Transportation

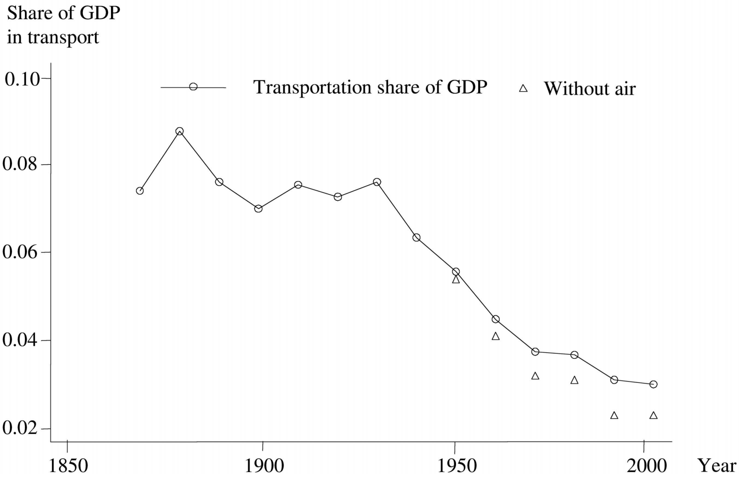


Fig. 1. The share of GDP in transportation industries. *Source:* Department of Commerce (since 1929), and Historical Statistics of the U.S. (Martin Series) before then

Secular Decline in Transport Costs

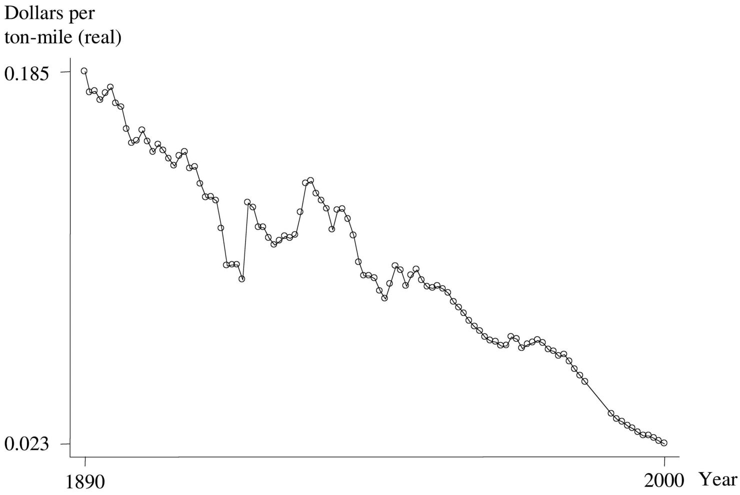


Fig. 3. The costs of railroad transportation over time. *Source:* Historical Statistics of the US (until 1970), 1994, Bureau of Transportation Statistics Annual Reports 1994 and 2002

Changing Means of Transportation

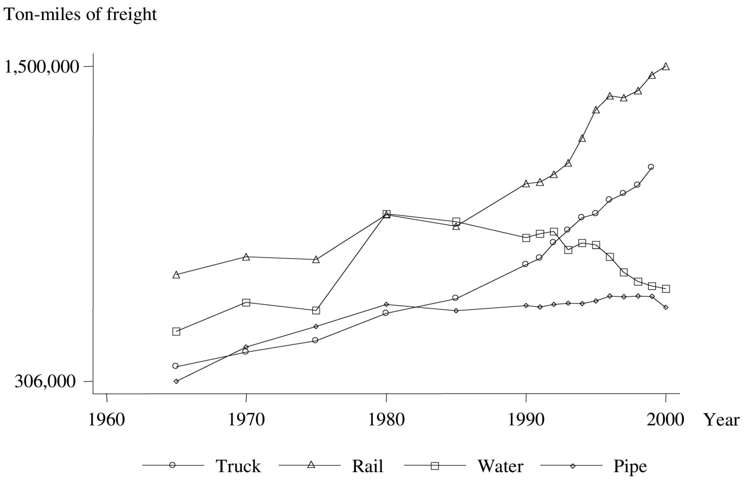


Fig. 6. Ton-miles of freight over time. *Source:* Bureau of Transportation Statistics Annual Reports

Post-War Cost Changes

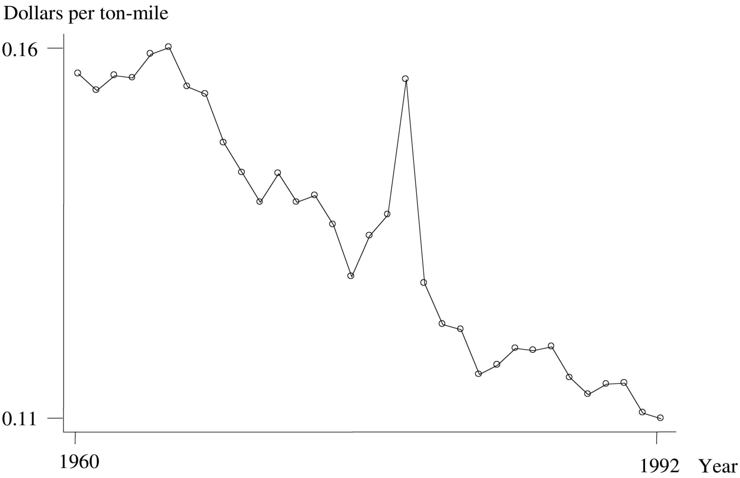


Fig. 5. Revenue per ton-mile, all modes together. *Source:* Bureau of Transportation Statistics Annual Reports

Transport Costs and Commodity Value

Table 1. Transportation costs and commodity value, selected industries

Commodity Description	Value ($ billion)	Ton-miles (billion)	Value per ton ($)	Average miles per shipment	Shipping costs/value (Rail)	Shipping costs/value (Truck)
Meat, fish, seafood, and their preparations	183.8	36.4	2,312	137	0.001	0.015
Milled grain products, preparations, and bakery products	109.9	48.5	1,069	122	0.003	0.029
Alcoholic beverages	87.9	27.8	1,085	58	0.001	0.013
Tobacco products	56.4	1.0	13,661	296	0.0005	0.006
Gasoline and aviation turbine fuel	217.1	136.6	225	45	0.005	0.052
Basic chemicals	159.6	136.8	539	332	0.014	0.160
Pharmaceutical products	224.4	5.6	22,678	692	0.0007	0.008
Chemical products and preparations (NEC)	209.5	45.0	2,276	333	0.004	0.038
Plastics and rubber	278.8	69.1	2,138	451	0.005	0.054
Wood products	126.4	96.9	384	287	0.018	0.194
Printed products	260.3	22.8	3,335	431	0.003	0.033
Textiles, leather, and articles of textiles or leather	379.2	24.7	8,266	912	0.003	0.028
Base metal in primary or semi finished forms and in finished basic shapes	285.7	117.5	851	276	0.008	0.084
Articles of base metal	227.2	48.7	2,133	403	0.005	0.049
Machinery	417.1	27.0	8,356	356	0.001	0.010
Electronic and electrical equipment, components and office equipment	869.7	27.1	21,955	640	0.0007	0.008
Motorised and other vehicles (including parts)	571.0	45.9	5,822	278	0.001	0.012

Source: National Transportation Statistics 2002 and authors' calculations assuming that the cost per ton-mile is 26 cents by truck and 2.4 cents by rail.

Transport Patterns Across Commodities

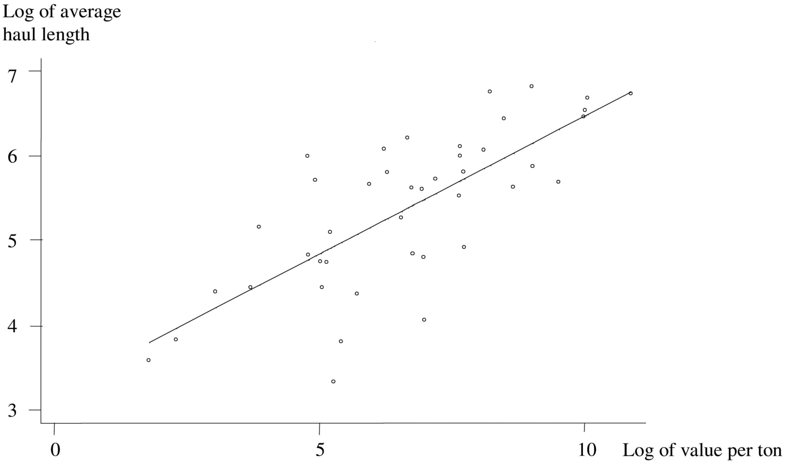


Fig. 7. Distance and value per ton. *Source:* National Transportation Statistics, 2001, Table 1-52

Implications of Declining Transport Costs for Goods

1. People are no longer tied to natural resources ▸ Employment ▸ Longitude
2. Consumer amenities are becoming more important ▸ Weather
3. Population is increasingly centralized in a few metropolitan regions
4. People are increasingly decentralized within those regions ▸ Table
5. High-density housing and public transportation are becoming increasingly irrelevant
6. Services are in dense areas; manufacturing is not ▸ Services ▸ Manufacturing
7. The location of manufacturing firms is not driven by proximity to customers or suppliers, the location of service firms is
8. Density and education go together ▸ Figure
9. Productivity may decline if congestion gets too high
    - Focus on transportation costs for people, not goods

Population Decline and Natural Resources

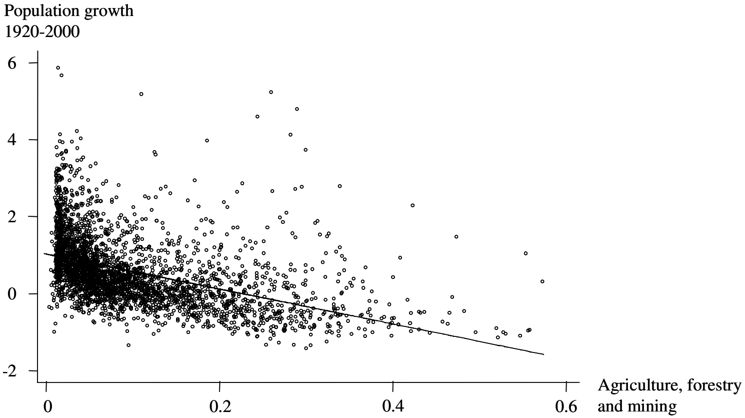


Fig. 10. Population decline and natural resources. *Source:* US Census, 1920, 1990 and 2000

$$\log\left(\frac{N_{2000}}{N_{1920}}\right) = \underset{(0.02)}{0.95} - \underset{(0.15)}{4.52}\,\frac{\text{Natural Resource Employment}}{\text{Total Employment}}$$

▸ Longitude ▸ Back

The Emptying of the Hinterland

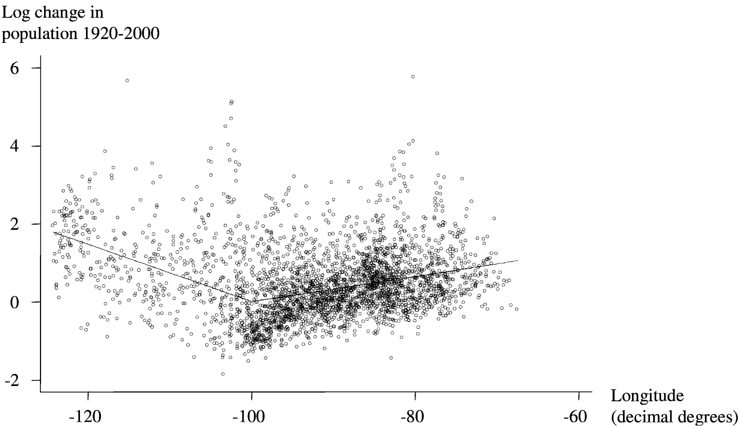


Fig. 11. The emptying of the hinterland, 1920–2000

$$\log\left(\frac{N_{2000}}{N_{1920}}\right) = -\underset{(0.35)}{7.3} - \underset{(0.003)}{0.07}\, L_{<-100^o} + \underset{(0.002)}{0.03}\, L_{>-100^o}$$

Employment | Back

The Growth of Temperate Places

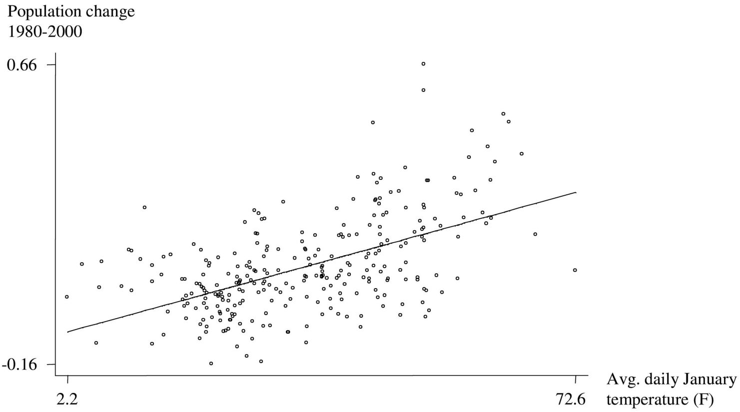


Fig. 12. The growth of temperate places, 1980–2000

$$\log\left(\frac{N_{2000}}{N_{1980}}\right) = \underset{(0.02)}{-0.08} - \underset{(0.0005)}{0.054}\ \text{Jan. Temp.}$$

Back

Distribution of U.S. Population by County Density

Year	Share of population in the least dense counties (bottom 50%)	Share of population in the dense counties (90–99th percentiles)	Share of population in the most dense counties (top 1%)
1920	19	30	20
1930	17	33	21
1940	17	34	20
1950	14	38	19
1960	11	43	17
1970	10	45	16
1980	10	45	13
1990	9	46	12
2000	9	49	11

Source: US Population Census, various years

Back

Services and Density

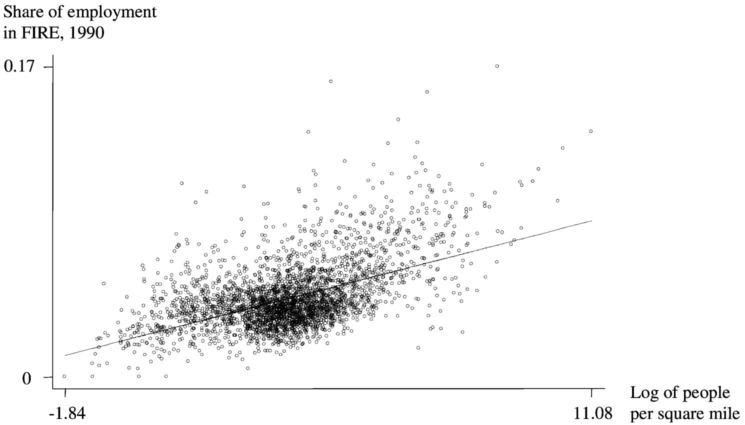


Fig. 13. Services and density

$$\frac{\text{Employment in FIRE}}{\text{Total Employment}} = \underset{(0.0007)}{0.023} + \underset{(0.00016)}{0.0057} \log \frac{N_{1990}}{L}$$

Back

Manufacturing and Density

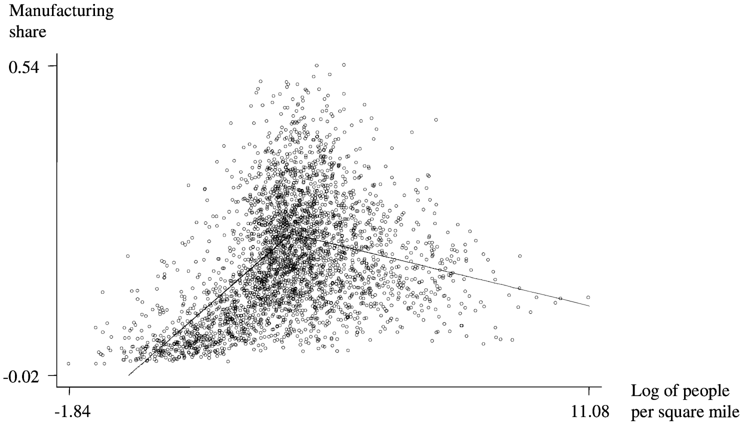


Fig. 14. Manufacturing and density

In the densest half: $\frac{\text{Employment in Mfg.}}{\text{Total Employment}} = \underset{(0.01)}{0.31} - \underset{(0.002)}{0.02} \log \frac{N_{1990}}{L}$

Back

Density and Education

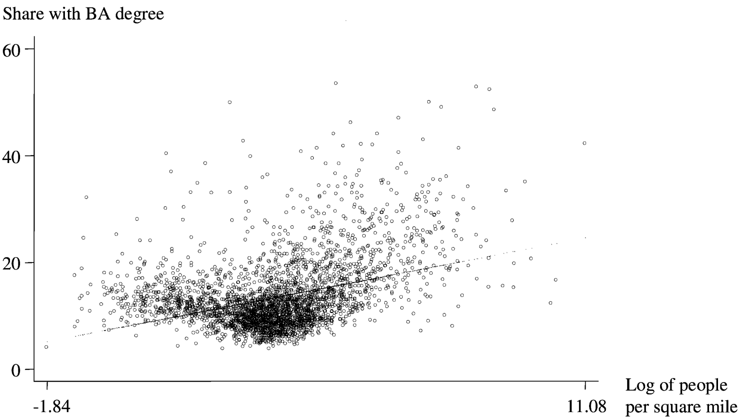


Fig. 15. Density and the share of the population with college degrees. *Source:* Department of Commerce (since 1929), and Historical Statistics of the US (Martin Series) before then

$$\frac{\text{Pop. w/ B.A. Degree}}{N} = \underset{(0.0026)}{0.079} + \underset{(0.00066)}{0.015} \log \frac{N_{1990}}{L}$$

Back