The Geography of Innovation in the United States

Weiliang Tan
Cornell University

Urban Economic Association European Meetings
March 28, 2025

Motivation and Research Questions

- The *central* question in **spatial economics**: what are the causes and consequences of the spatial distribution of economic activity?

Motivation and Research Questions

- The *central* question in **spatial economics**: what are the causes and consequences of the spatial distribution of economic activity?

- This paper focuses on **innovation**, primarily measured using patents

Motivation and Research Questions

- The *central* question in **spatial economics**: what are the causes and consequences of the spatial distribution of economic activity?

- This paper focuses on **innovation**, primarily measured using patents

- Rising spatial concentration in the United States is well-known

Motivation and Research Questions

- The *central* question in **spatial economics**: what are the causes and consequences of the spatial distribution of economic activity?
- This paper focuses on **innovation**, primarily measured using patents
- Rising spatial concentration in the United States is well-known

Motivation and Research Questions

- The *central* question in **spatial economics**: what are the causes and consequences of the spatial distribution of economic activity?
- This paper focuses on **innovation**, primarily measured using patents
- Rising spatial concentration in the United States is well-known
- Yet, fundamental questions on the geography of innovation remain unanswered:

Motivation and Research Questions

- The *central* question in **spatial economics**: what are the causes and consequences of the spatial distribution of economic activity?
- This paper focuses on **innovation**, primarily measured using patents
- Rising spatial concentration in the United States is well-known
- Yet, fundamental questions on the geography of innovation remain unanswered:

1. **What factors drive the rising spatial concentration of innovation?**

Motivation and Research Questions

- The *central* question in **spatial economics**: what are the causes and consequences of the spatial distribution of economic activity?
- This paper focuses on **innovation**, primarily measured using patents
- Rising spatial concentration in the United States is well-known
- Yet, fundamental questions on the geography of innovation remain unanswered:

1. **What factors drive the rising spatial concentration of innovation?**
2. **What are its consequences on spatial and aggregate growth?**

Data: Measuring the Geography of Innovation

- Universe of patents from PatentsView from 1976-2018
  - Map patents to **Commuting Zones** (CZs) using inventor home addresses, which I geocode using the Google Maps API
  - Map technology classes to **fields and subfields**, building on the methodology used by the World Intellectual Property Organization

$\Longrightarrow$ **Produce a new measure of local innovation**: $\frac{\text{CZ Patent Share}}{\text{CZ Population Share}}$

Data: Measuring the Geography of Innovation

- Universe of patents from PatentsView from 1976-2018
  - Map patents to **Commuting Zones** (CZs) using inventor home addresses, which I geocode using the Google Maps API
  - Map technology classes to **fields and subfields**, building on the methodology used by the World Intellectual Property Organization

$\Longrightarrow$ **Produce a new measure of local innovation**: $\frac{\text{CZ Patent Share}}{\text{CZ Population Share}}$

- Universe of firms and plants in the US Census Longitudinal Business Database
  - Map patent assignees to **firms** using Kerr and Fu (2008) and Dreisigmeyer et al (2018)

- Firms and plants from Dun and Bradstreet's National Establishment Time Series Database (NETS)
  - Map patent assignees to firms following Hughes et al (2021)

What drives the rising spatial concentration of innovation?

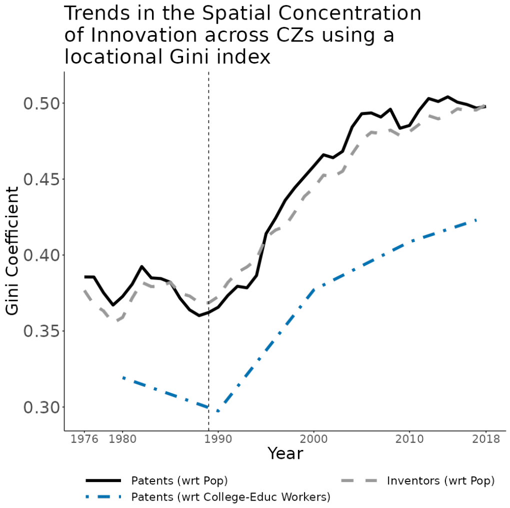
- When and where: innovation became more concentrated in **high-skill CZs** (not large or dense CZs) after **1990**

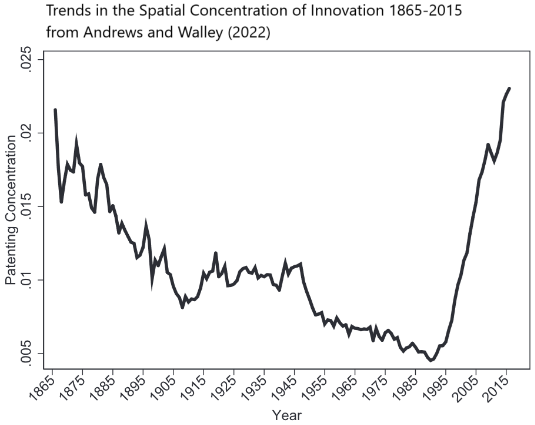
- Why: **ICT shock** around 1990

  1. **Increase in ICT research productivity** (four breakthrough ICT patents 1985-1987)
     - Colocation of ICT production and innovation $\Longrightarrow$ $\uparrow$ ICT patents in high-skill CZs
     - Spillovers from ICT to non-ICT innovation $\Longrightarrow$ $\uparrow$ non-ICT patents in high-skill CZs

  2. **Reduced communication costs**
     - Asymmetric scale effect: firms in high-skill CZs disproportionately expanded production to lower-cost locations $\Longrightarrow$ $\uparrow$ non-ICT patents in high-skill CZs

Innovation became more spatially concentrated **after 1990**

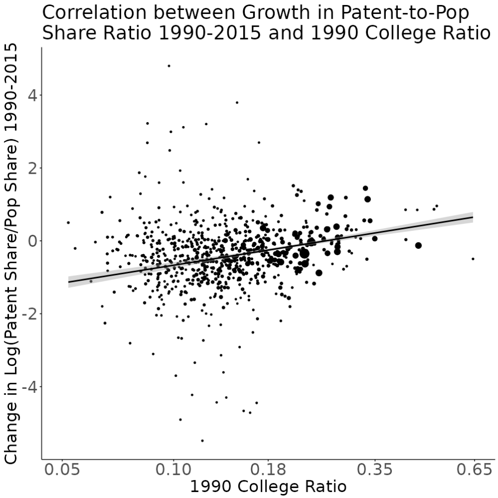


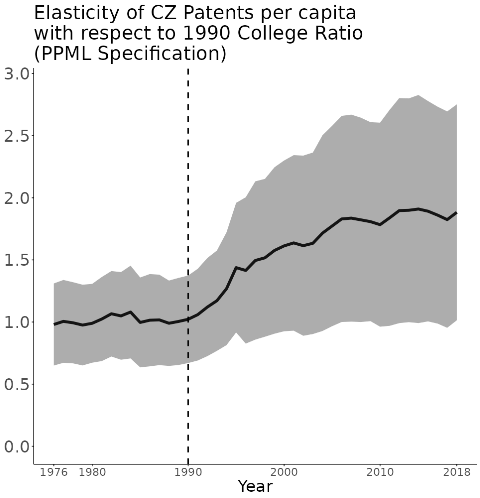


▸ Drop Top Patenting CZs

▸ Alternative Measures

Innovation became more concentrated in **high-skill CZs** after 1990



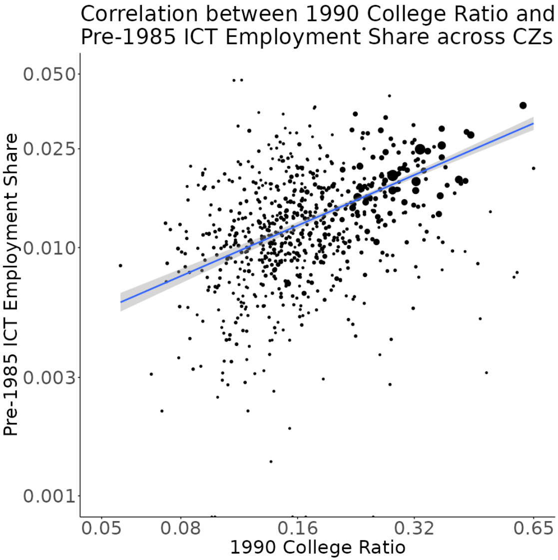


$$\text{Log Patents pc}_{r,t} = \alpha_t \cdot \text{Log 1990 College Ratio}_r \times \text{Year}_t + \gamma_t + \epsilon_{r,t}$$

▸ Log-Log Specification ▸ Absence of Sorting by Pop or Density ▸ Map ▸ Evolution from 1980: Contrast against Worker Sorting

Connecting the Rising Patent Concentration to ICT

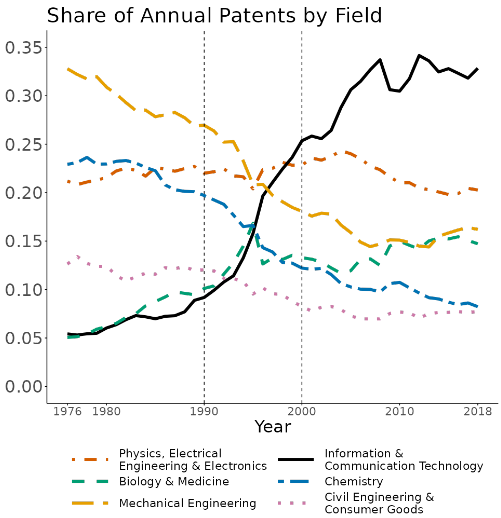
High-skill CZs had a higher pre-1985 ICT employment share

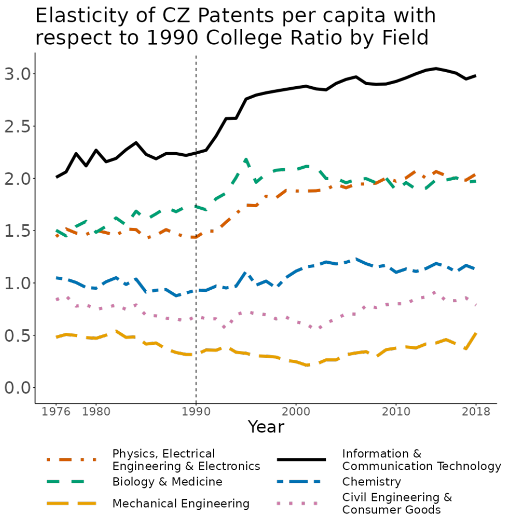


▸ Pre-1990 ICT Employment Share

Connecting the Rising Patent Concentration to ICT

Decomposition across Technology Fields





▸ Formal Decomposition

▸ ICT vs non-ICT

What drives the rising spatial concentration of innovation?

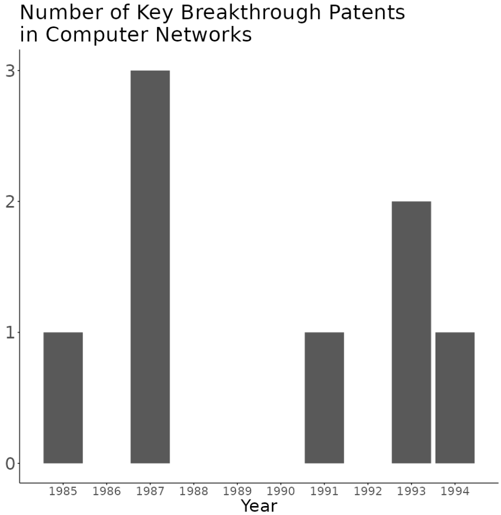
- When and where: innovation became more concentrated in **high-skill CZs** (not large or dense CZs) after **1990**

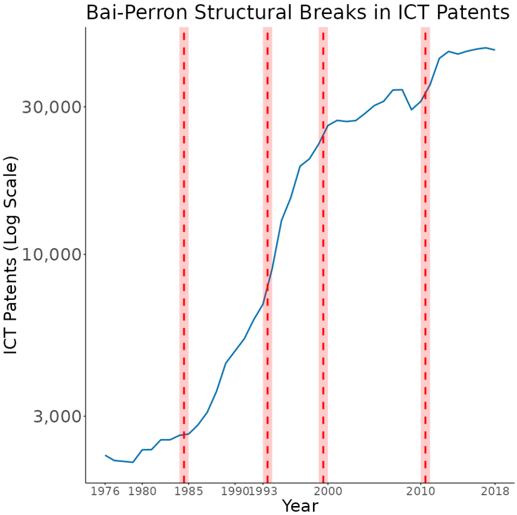
Why: **ICT shock** around 1990 (eight key patents in computer networks)

1. **Increased ICT research productivity**
   - **Colocation** of ICT production and innovation $\implies \uparrow$ ICT patents in high-skill CZs
   - **Spillovers** from ICT to non-ICT innovation $\implies \uparrow$ non-ICT patents in high-skill CZs
2. **Reduced communication costs**
   - **Asymmetric scale effect**: firms in high-skill CZs disproportionately expanded production to more CZs $\implies \uparrow$ non-ICT patents in high-skill CZs

Defining the ICT Shock

Eight key patents in computer networks identified by Kelly et al 2021





▸ Connecting Breakthroughs to ICT Patent Growth ▸ Alternative Definition of the ICT Shock ▸ Structural Breaks in Other Patent Trends

Colocation of ICT Innovation and Production

CZs with higher pre-1985 ICT emp shares: greater post-shock ↑ in ICT patents and employment

$$\text{Outcome}_{r,t} = \beta \cdot \text{ Pre-1985 ICT Employment Share}_r \times \text{Growth of National ICT Patents}_t + \gamma_r + \gamma_t + \varepsilon_{r,t}$$

Dependent Variables:	ICT Patents	ICT Patents per capita	ICT Employment	ICT Employment Share
Model:	(1)	(2)	(3)	(4)
Pre-1985 ICT Employment Share$_r\times$	3,792.9***	0.6169***	43,396.9***	-0.0084
Growth of National ICT Patents$_t$	(1,107.4)	(0.2164)	(15,192.5)	(0.0086)
Fixed-effects				
CZ	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Observations	24,548	24,548	24,548	24,544
R^2	0.74282	0.73925	0.95520	0.80472
Within R^2	0.12092	0.03917	0.06345	0.00608

Clustered (CZ) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

▸ Using Levels of National ICT Patents ▸ Regression After 1990 ▸ Firm-Level Evidence

Spillovers from ICT to Non-ICT Innovation after 1990

CZs with higher pre-1990 ICT employment shares: greater ↑ in non-ICT patents

$$\text{Outcome}_{r,t} = \kappa \cdot \text{ Pre-1990 ICT Employment Share}_r \times \text{Growth of National ICT Patents}_t + \gamma_r + \gamma_t + \varepsilon_{r,t}$$

Dependent Variables:	Non-ICT Patents	Non-ICT Patents per capita
Model:	(1)	(2)
Pre-1990 ICT Employment Share$_r$× Growth of National ICT Patents$_t$	632.5***	0.0814*
	(238.5)	(0.0444)
Fixed-effects		
CZ	Yes	Yes
Year	Yes	Yes
Observations	20,938	20,938
R^2	0.94696	0.88179
Within R^2	0.10189	0.02474

Clustered (CZ) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

▸ Using Levels of National ICT Patents ▸ Using Pre-1985 ICT Emp Shares

What drives the rising spatial concentration of innovation?

- When and where: innovation became more concentrated in **high-skill CZs** (not large or dense CZs) after **1990**

Why: **ICT shock** around 1990 (eight key patents in computer networks)

1. **Increased ICT research productivity**
   - Colocation of ICT innovation and production $\implies \uparrow$ ICT innovation in high-skill CZs
   - Spillovers from ICT to non-ICT innovation $\implies \uparrow$ ICT innovation in high-skill CZs

2. **Reduced communication costs**
   - **Asymmetric scale effect**: firms in high-skill CZs disproportionately expanded production to more CZs and produced more non-ICT patents after 1990

The Key Computer Network Patents Reduced Communication Costs

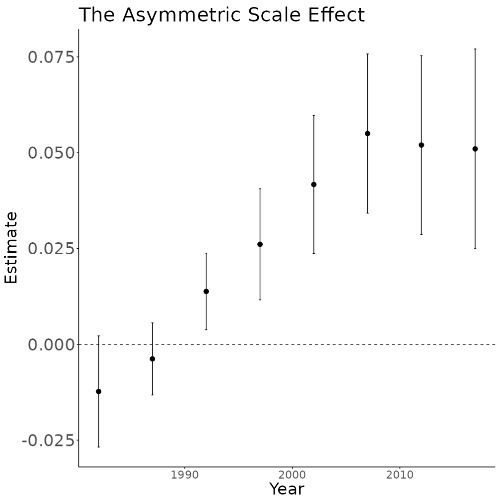
Selected patents from the eight identified by Kelly et al (2021)

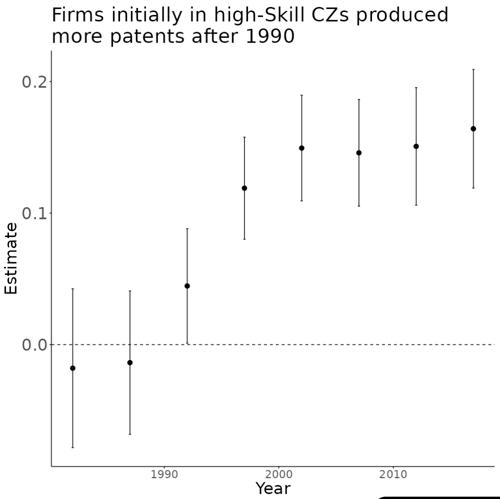
Patent No.	Year	Title	Assignee	Inventors	Citations
4,800,488	1985	Method of Propagating Resource Information in a Computer Network	AT&T Bell Lab	Rakesh Agrawal, Ahmed K Ezzat	150
4,823,338	1987	Virtual Local Area Network	AT&T Info Systems; AT&T Company	Kenneth K Chan, Argyrios C Milonas, Terry G Lyons, Philip W Hartmann, P Lamons	151
4,887,204	1987	System and Method for Accessing Remote Files in a Distributed Networking Environment	IBM	Donavon W Johnson, Grover H Neuman, Charles H Sauer, Amal A Shaheen-Gouda, Todd A Smith	341
5,249,290	1991	Method of and apparatus for operating a client/server computer network	AT&T Bell Lab	Issac J Heizer	205
5,341,477	1993	Broker for Computer Network Server Selection	Digital Equipment Corporation (known as HP today)	Richard P Pitkin, John P Morency	792

The Asymmetric Scale Effect and Rising Patent Concentration

Firms in high-skill CZs **expanded into more CZs and produced more non-ICT patents after 1990**

$$\text{Outcome}_{f,t} = \delta_t \cdot \text{1987 Employment Elasticity}_f \times \text{Year}_t + \zeta \cdot \text{1987 Firm Size}_f + \omega \cdot \text{1987 Firm Spatial Scope}_f + \gamma_t + \epsilon_{f,t}$$





▸ Firm Decomposition

DYNAMIC SPATIAL MODEL WITH *ENDOGENOUS AND DIRECTED INNOVATION*

Goals of the Model

1. Formalize how the **ICT shock** $\Longrightarrow$ **geography of innovation**
   - Aspects of the shock: (1) Increased ICT research productivity; (2) Reduced communication costs
   - Mechanisms: (1) **Colocation**; (2) **Spillovers**; (3) **Asymmetric scale effect**
2. Examine how the **geography of innovation** $\Longrightarrow$ **aggregate growth and welfare**

Goals of the Model

1. Formalize how the **ICT shock** $\implies$ **geography of innovation**
   - Aspects of the shock: (1) Increased ICT research productivity; (2) Reduced communication costs
   - Mechanisms: (1) **Colocation**; (2) **Spillovers**; (3) **Asymmetric scale effect**
2. Examine how the **geography of innovation** $\implies$ **aggregate growth and welfare**

Requires a model with:

- Different regions
- Different sectors (ICT and non-ICT)
- Innovation, slow diffusion, production, costly trade
- Geography of innovation evolving endogenously through the 3 mechanisms

Goals of the Model

1. Formalize how the **ICT shock** $\implies$ **geography of innovation**
   - Aspects of the shock: (1) Increased ICT research productivity; (2) Reduced communication costs
   - Mechanisms: (1) **Colocation**; (2) **Spillovers**; (3) **Asymmetric scale effect**
2. Examine how the **geography of innovation** $\implies$ **aggregate growth and welfare**

Requires a model with:

- Different regions
- Different sectors (ICT and non-ICT)
- Innovation, slow diffusion, production, costly trade
- Geography of innovation evolving endogenously through the 3 mechanisms

$\implies$ Develop a theory of ***endogenous and directed innovation*** across space

Mechanics of the Model

I introduce ***endogenous and directed innovation*** into quantitative spatial models via two model components:

Mechanics of the Model

I introduce ***endogenous and directed innovation*** into quantitative spatial models via two model components:

1. *Idea-level* **endogenous innovation integrated with technology diffusion**
    - Apply techniques from Eaton and Kortum (2024) to clarify Lind and Ramondo (2024) then introduce imperfect competition

$\implies$ Profits from innovation depend on trade and technology adoption

Mechanics of the Model

I introduce ***endogenous and directed innovation*** into quantitative spatial models via two model components:

1. *Idea-level* **endogenous innovation integrated with technology diffusion**
   - Apply techniques from Eaton and Kortum (2024) to clarify Lind and Ramondo (2024) then introduce imperfect competition

   $\Longrightarrow$ Profits from innovation depend on trade and technology adoption

2. **Dynamic worker mobility** across regions and sectors and between production and research (extends Caliendo et al 2019)

   $\Longrightarrow$ Workers respond to changes in relative innovation profits across regions

The Spatial Direction of Innovation

- **Proposition 1**: On the transition path, the ***spatial direction of innovation*** is governed by:

$$\frac{\omega^{k,R}_{r,t^*}}{\omega^{k,R}_{r',t^*}} = \underbrace{\frac{A_{r,t^*}}{A_{r',t^*}}}_{\substack{\text{fundamental}\\\text{research}\\\text{productivity}\\\text{(function of}\\\textbf{college ratio)}}} \cdot \underbrace{\frac{T^k_{r,t^*}}{T^k_{r',t^*}}}_{\substack{\text{relative}\\\text{technology}\\\text{levels}}} \cdot \underbrace{\left(\frac{L^{k,G}_{r,t^*}}{L^{k,G}_{r',t^*}}\right)^{\eta}}_{\substack{\text{benefits of}\\\textbf{colocation of}\\\textbf{innovation and}\\\textbf{production}}} \cdot \underbrace{\left(\frac{L^{R}_{r,t^*}}{L^{R}_{r',t^*}}\right)^{\alpha}}_{\substack{\text{agglomeration}\\\text{economies in}\\\text{innovation}\\\text{including}\\\textbf{spillovers from}\\\textbf{ICT to non-ICT}}} \cdot \underbrace{\frac{\int_{t^*}^{\infty} e^{-\zeta(t-t^*)} \sum_{d=1}^{N} \frac{\boldsymbol{\phi_{rd,t^*t}}}{\lambda_{r,t^*}} \frac{Y_{d,t}}{1+\theta} \frac{1}{P_{r,t}} dt}{\int_{t^*}^{\infty} e^{-\zeta(t-t^*)} \sum_{d=1}^{N} \frac{\boldsymbol{\phi_{r'd,t^*t}}}{\lambda_{r',t^*}} \frac{Y_{d,t}}{1+\theta} \frac{1}{P_{r',t}} dt}}_{\substack{\text{expected market potential of an idea,}\\\text{with the idea market shares capturing}\\\text{the }\textbf{asymmetric scale effect}}}$$

Balanced Growth Path

Steady state **geography of innovation** $\rightarrow$ **aggregate growth**

- **Proposition 2**: On the balanced growth path, the growth rate g^k of technology in each sector is given by:

$$\dot{T}_o^k(t) = \sum_l \boldsymbol{\gamma_l^k} T_l^k(t) \int_{-\infty}^{t} \boldsymbol{g^k} e^{-\boldsymbol{g^k}(t-t^*)} \left(1 - e^{-\delta_{l'o',t'}(t-t')}\right)^{1-\rho} dt^*$$

prices are falling at rate:

$$g_p = -\frac{1}{\theta} \sum_k \iota^k \boldsymbol{g^k}$$

and the **aggregate growth rate** of the expected value of workers is:

$$g_v = \frac{1+\zeta}{\zeta} \frac{1}{\theta} \sum_k \iota^k \boldsymbol{g^k}$$

Conclusion

- Answer the perennial question of what drives the rising spatial concentration of innovation in the US:
  - Innovation became more concentrated in **high-skill CZs** after **1990** primarily due to the **ICT shock** via the following mechanisms:
    1. Colocation of innovation and production in the ICT sector
    2. Spillovers from ICT to non-ICT innovation
    3. Asymmetric scale effect: firms in initially in high-skill CZs disproportionately expanded to lower-cost locations

Conclusion

- Answer the perennial question of what drives the rising spatial concentration of innovation in the US:
  - Innovation became more concentrated in **high-skill CZs** after **1990** primarily due to the **ICT shock** via the following mechanisms:
    1. **Colocation** of innovation and production in the ICT sector
    2. **Spillovers** from ICT to non-ICT innovation
    3. **Asymmetric scale effect**: firms in initially in high-skill CZs disproportionately expanded to lower-cost locations

- Introduce ***endogenous and directed innovation*** into quantitative spatial models to:
  - Formalize how the **ICT shock** $\implies$ **geography of innovation**
  - Illustrate how the **geography of innovation** $\implies$ **aggregate growth and welfare**

Conclusion

- Answer the perennial question of what drives the rising spatial concentration of innovation in the US:
  - Innovation became more concentrated in **high-skill CZs** after **1990** primarily due to the **ICT shock** via the following mechanisms:
    1. **Colocation** of innovation and production in the ICT sector
    2. **Spillovers** from ICT to non-ICT innovation
    3. **Asymmetric scale effect**: firms in initially in high-skill CZs disproportionately expanded to lower-cost locations

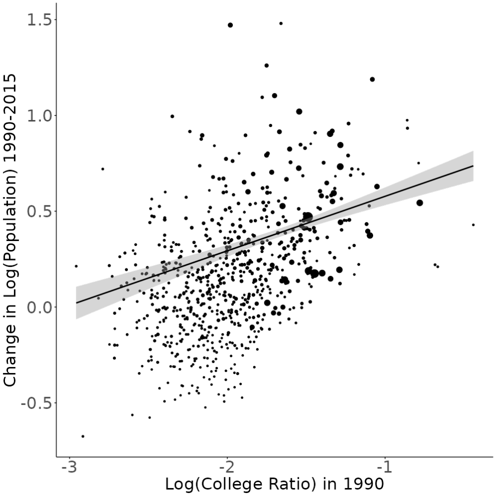
- Introduce ***endogenous and directed innovation*** into quantitative spatial models to:
  - Formalize how the **ICT shock** $\Longrightarrow$ **geography of innovation**
  - Illustrate how the **geography of innovation** $\Longrightarrow$ **aggregate growth and welfare**

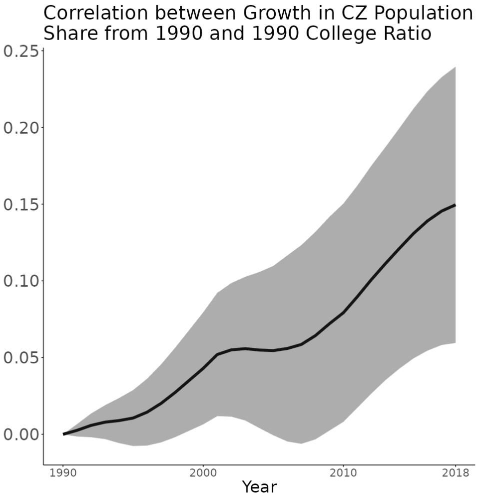
- Mechanics: Put the microfoundations of the Eaton-Kortum structure (Eaton and Kortum, 2024) at the center of quantitative spatial models

APPENDIX

EMPIRICAL APPENDIX

Worker Migration to High-Skill Cities

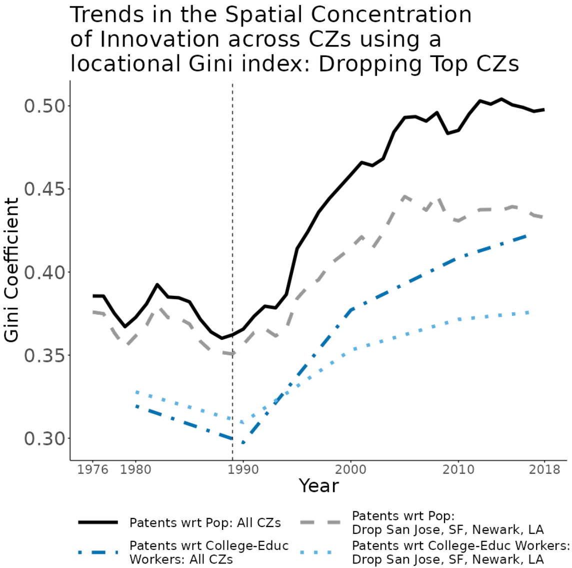




◂ Main Analysis

Innovation became more spatially concentrated **after 1990**

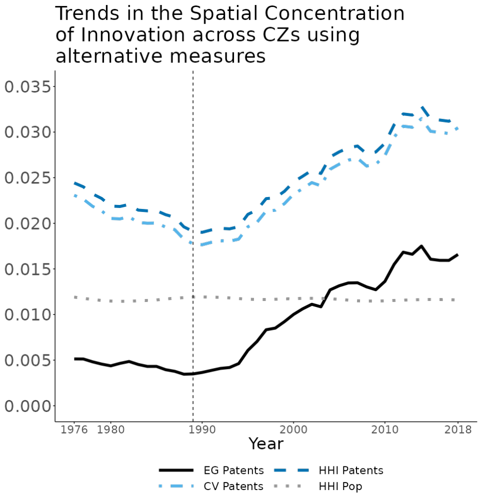
Drop top patenting CZs



◂ Main Fact

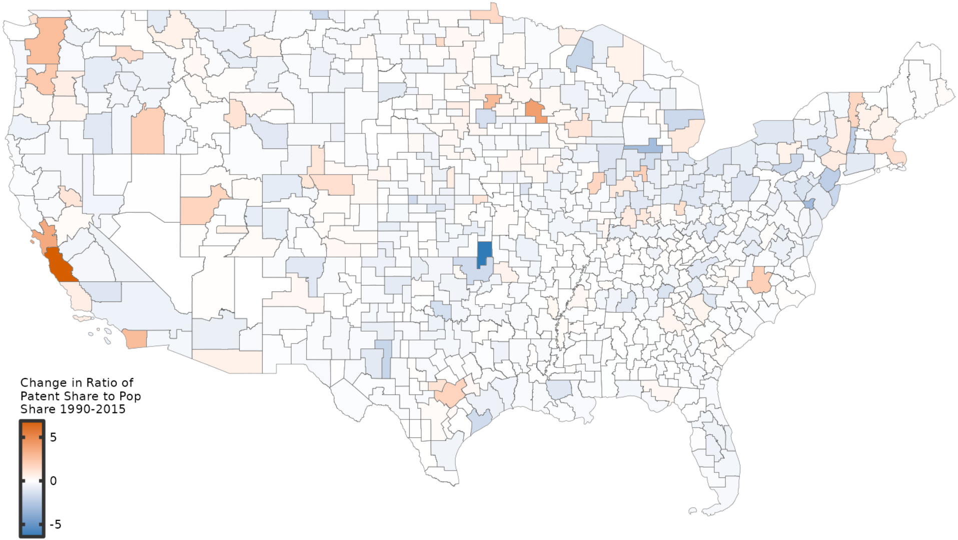
Innovation became more spatially concentrated **after 1990**

Alternative measures of spatial concentration



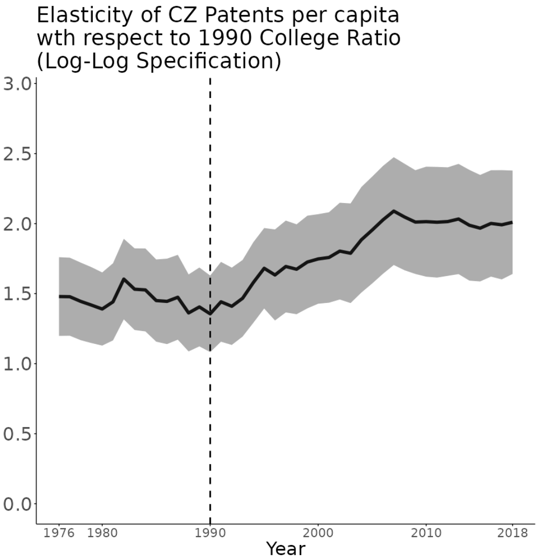
Main Fact

Innovation became more concentrated in **high-skill CZs** after 1990



◂ Trends in Patent Sorting

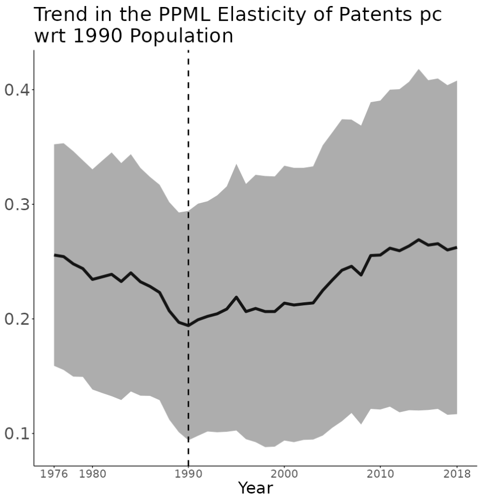
Innovation became more concentrated in **high-skill CZs** after 1990

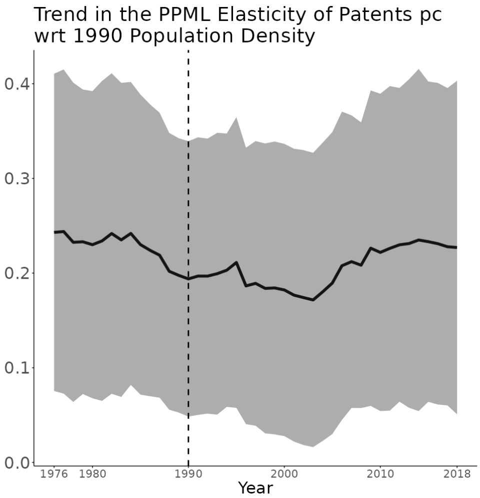


$$\text{Log Patents pc}_{r,t} = \alpha_t \cdot \text{Log 1990 College Ratio}_r \times \text{Year}_t + \gamma_t + \epsilon_{r,t}$$

◂ Main Fact

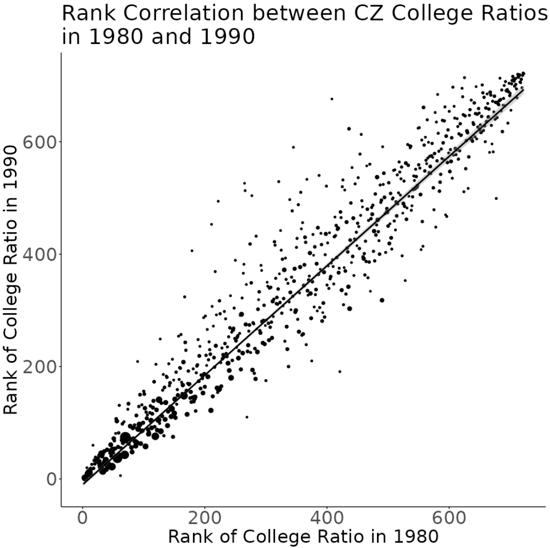
Absence of patent sorting by 1990 population or population density





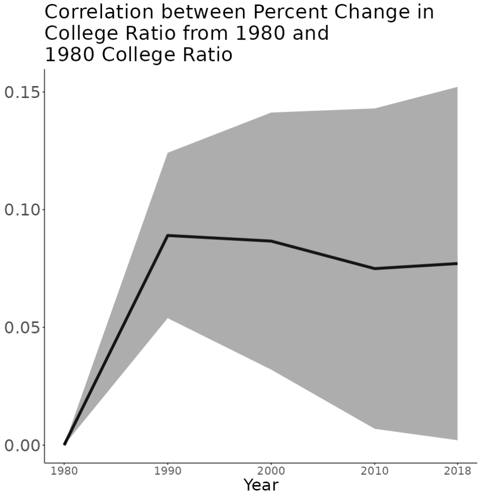
Patent Sorting by 1990 College Ratio

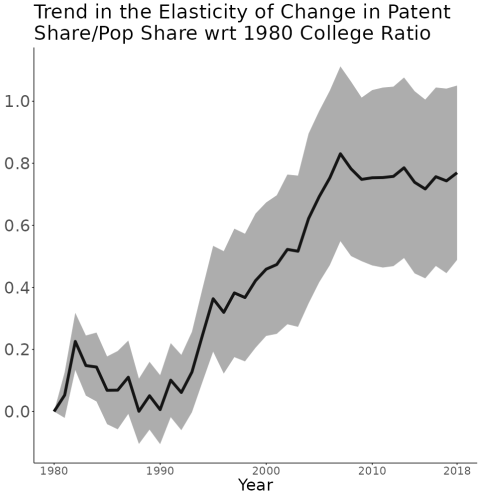
The rank order of CZs by college ratio was similar in 1980 and 1990



◂ Main Fact

Worker sorting primarily occurred from 1980 to 1990

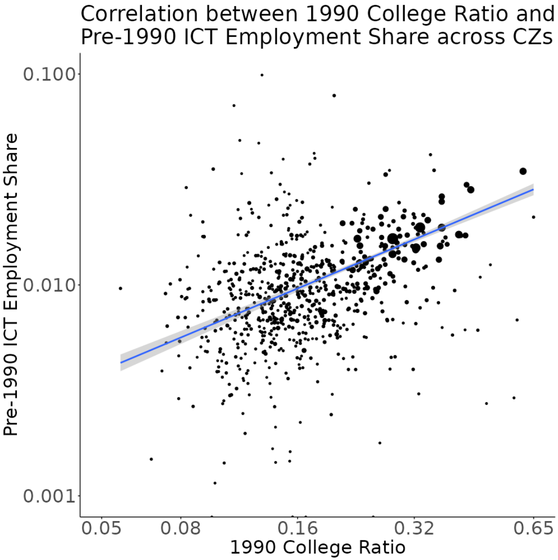




Main Fact

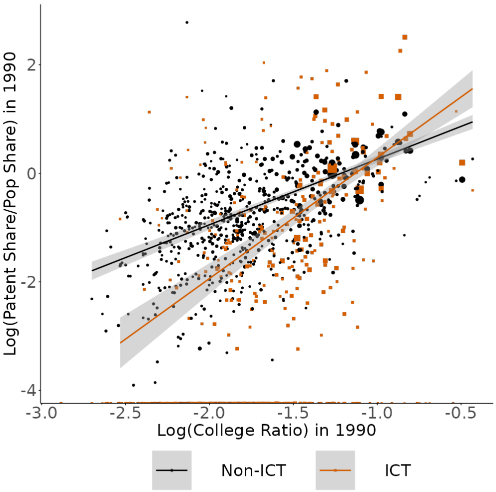
Connecting the Rising Patent Concentration to ICT

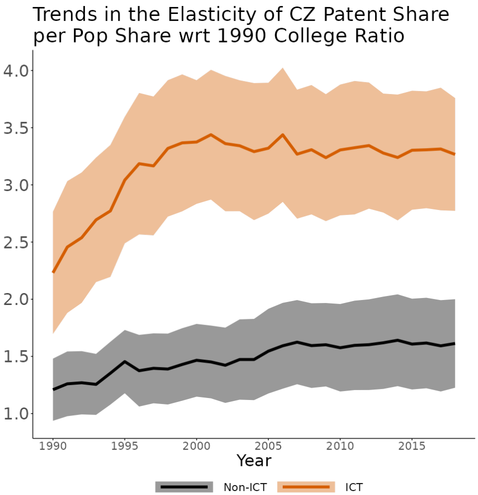
High-skill CZs had a higher pre-1990 ICT employment share



◂ Pre-1985 ICT Employment Share

Comparison between ICT and Non-ICT Patent Elasticity



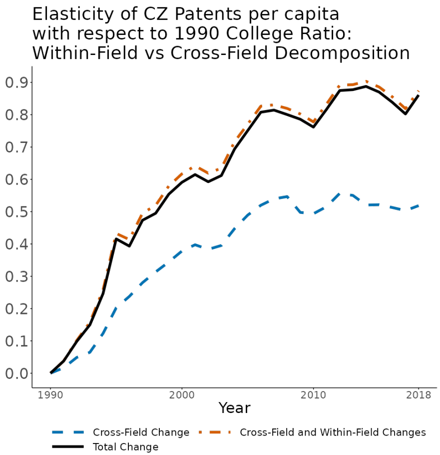


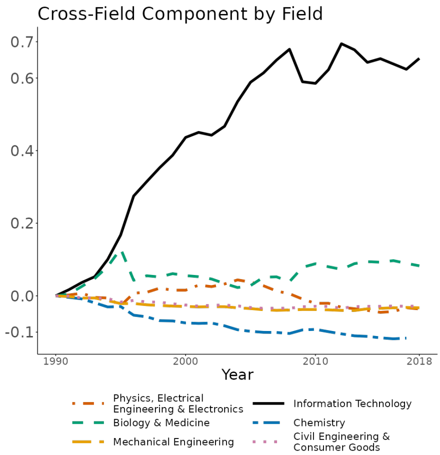
◂ Main Fact

Field Decomposition of Patent Elasticity

Shift to ICT accounts for 53% of the overall rising concentration in high-skill cities from 1990

$$\alpha_{t^*} - \alpha_{1990} = \sum_{t=1991}^{t=t^*} \Delta\alpha_t = \sum_{t=1991}^{t=t^*} \left[\underbrace{\sum_f \bar{\alpha}_{f,t} \Delta s_{f,t}}_{\text{changes in field composition}} + \underbrace{\sum_f \bar{s}_{f,t} \Delta\alpha_{f,t}}_{\text{within-field changes}} + \underbrace{\Delta\left(\alpha_t - \sum_f s_{f,t}\alpha_{f,t}\right)}_{\text{residual: changes in the colocation of fields}} \right]$$



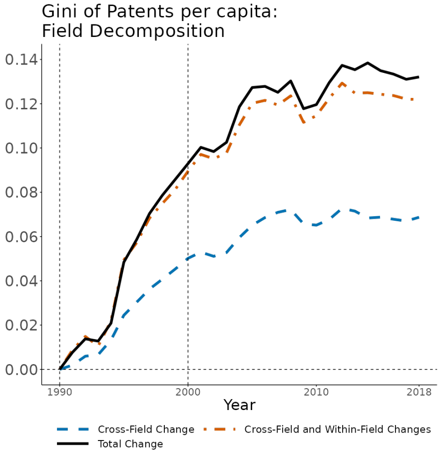


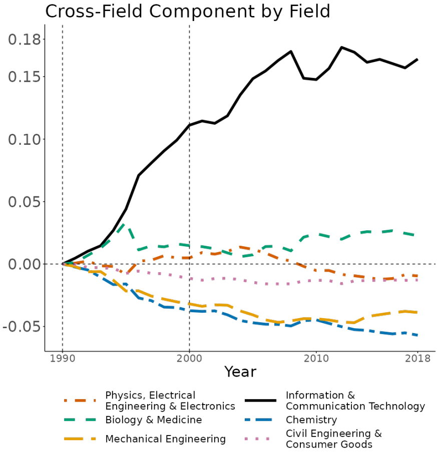
Main Fact

Field Decomposition of Patent Gini

Shift to ICT accounts for 54% of the overall rising concentration from 1990

$$G_{t^*} - G_{1990} = \sum_{t=1991}^{t=t^*} \Delta G_t = \sum_{t=1991}^{t=t^*} \left[\underbrace{\sum_f \overline{G}_{f,t} \Delta s_{f,t}}_{\text{changes in field composition}} + \underbrace{\sum_f \overline{s}_{f,t} \Delta G_{f,t}}_{\text{within-field changes}} + \underbrace{\Delta\left(G_t - \sum_f s_{f,t} G_{f,t}\right)}_{\text{residual: changes in the colocation of fields}} \right]$$

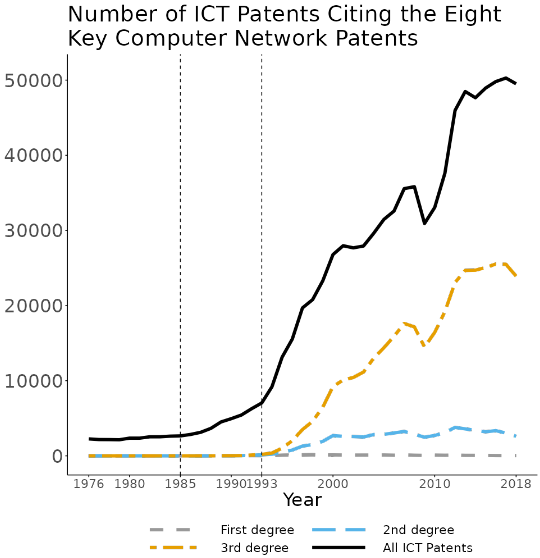




Main Fact

Defining the ICT Shock

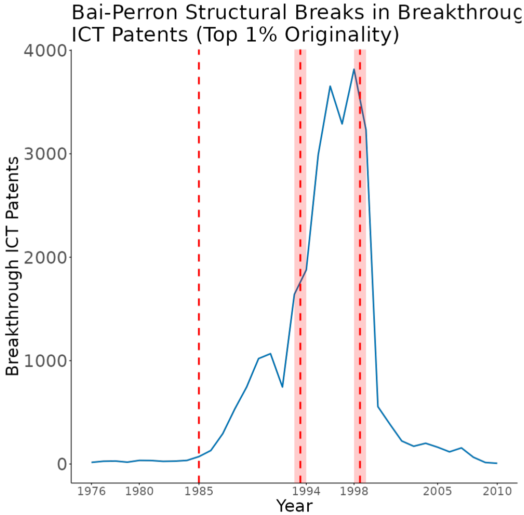
Connecting the eight key patents in computer networks with ICT patent growth



Definition of the ICT Shock

Defining the ICT Shock

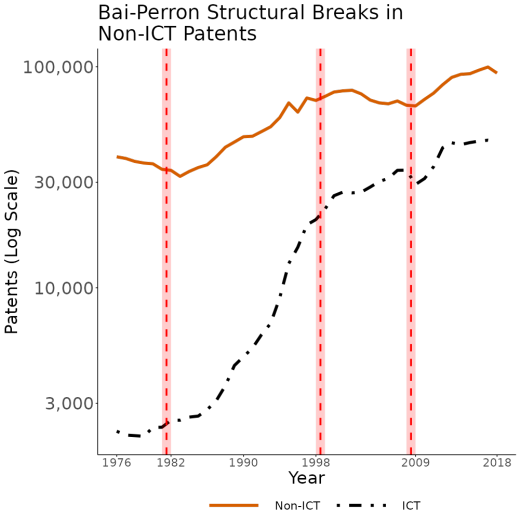
Alternative definition: ICT patents with top 1% originality scores from Kelly et al 2021

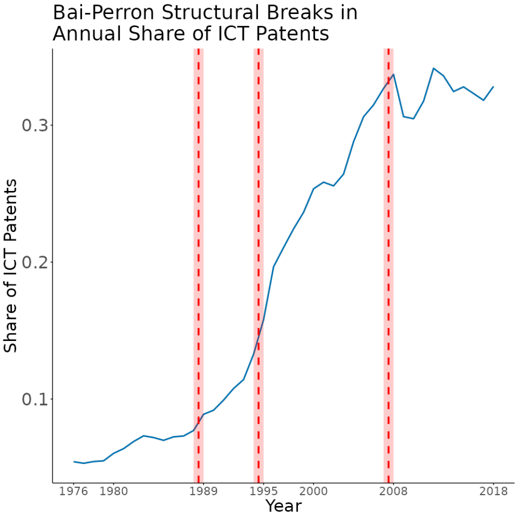


◂ Main Definition of the ICT Shock

Defining the ICT Shock

Structural breaks in other patent trends





Definition of the ICT Shock

Colocation of ICT Innovation and Production

CZs with higher pre-1985 ICT emp shares: greater post-shock ↑ in ICT patents and employment

$$\text{Outcome}_{r,t} = \beta \cdot \text{ Pre-1985 ICT Employment Share}_r \times \textbf{Level} \text{ of National ICT Patents}_t + \gamma_r + \gamma_t + \varepsilon_{r,t}$$

Dependent Variables:	ICT Patents	ICT Patents per capita	ICT Employment	ICT Emp Share
Model:	(1)	(2)	(3)	(4)
Pre-1985 ICT Employment Share$_r$×	1.458***	0.0002***	16.69***	-3.25×10^{-6}
Level of National ICT Patents$_t$	(0.4258)	(8.32×10^{-5})	(5.841)	(3.33×10^{-6})
Fixed-effects				
CZ	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Observations	24,548	24,548	24,548	24,544
R^2	0.74282	0.73925	0.95520	0.80472
Within R^2	0.12092	0.03917	0.06345	0.00608

Clustered (CZ) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Main Specification

Colocation of ICT Innovation and Production

CZs with higher pre-1990 ICT emp shares: greater post-shock ↑ in ICT patents and employment

$$\text{Outcome}_{r,t} = \beta \cdot \text{ Pre-1990 ICT Employment Share}_r \times \text{Growth of National ICT Patents}_t + \gamma_r + \gamma_t + \varepsilon_{r,t}$$

Dependent Variables:	ICT Patents	ICT Patents per capita	ICT Employment	ICT Employment Share
Model:	(1)	(2)	(3)	(4)
Pre-1990 ICT Employment Share$_r$×	8,334.9***	1.474***	77,372.4***	-0.0247
Growth of National ICT Patents$_t$	(2,735.3)	(0.5416)	(28,464.3)	(0.0204)
Fixed-effects				
CZ	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Observations	20,938	20,938	20,938	20,934
R^2	0.81282	0.81900	0.96195	0.83343
Within R^2	0.15934	0.06459	0.05407	0.01308

Clustered (CZ) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

◂ Main Specification

Colocation of ICT Innovation and Production

CZs with higher pre-1990 ICT emp shares: greater post-shock ↑ in ICT patents and employment

$$\text{Outcome}_{r,t} = \beta \cdot \text{ Pre-1990 ICT Employment Share}_r \times \textbf{Level} \text{ of National ICT Patents}_t + \gamma_r + \gamma_t + \varepsilon_{r,t}$$

Dependent Variables:	ICT Patents	ICT Patents per capita	ICT Employment	ICT Emp Share
Model:	(1)	(2)	(3)	(4)
Pre-1990 ICT Employment Share$_r \times$	1.872^{***}	0.0003^{***}	17.38^{***}	-5.54×10^{-6}
Level of National ICT Patents$_t$	(0.6144)	(0.0001)	(6.394)	(4.58×10^{-6})
Fixed-effects				
CZ	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Observations	20,938	20,938	20,938	20,934
R^2	0.81282	0.81900	0.96195	0.83343
Within R^2	0.15934	0.06459	0.05407	0.01308

Clustered (CZ) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Main Specification

Colocation of ICT Innovation and Production

Within firms and firm-CZs, ICT patents are correlated with ICT employment share

Dependent Variables:	ICT Patents		Non-ICT Patents	
Model:	(1)	(2)	(3)	(4)
Emp Share in ICT$_{f,r,t}$ × After 1990	**0.0474**	**0.1734***	-0.5885*	0.0899
	(0.3855)	(0.0910)	(0.3129)	(0.1260)
Emp Share in R&D$_{f,r,t}$ × After 1990	1.446***	0.1529**	1.696***	0.2350***
	(0.2556)	(0.0600)	(0.2052)	(0.0675)
Emp Share in ICT$_{f,r,t}$ × Emp Share in R&D$_{f,r,t}$	**6.976*****	**1.341****	6.284***	0.2761
× After 1990	(0.8954)	(0.5218)	(1.478)	(0.7667)
Firm-Year	Yes	Yes	Yes	Yes
CZ-Year		Yes		Yes
Firm-CZ		Yes		Yes
Observations	1,200,983	255,573	2,769,075	893,019

Clustered (firm & CZ) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

◂ Region-Level Evidence

Colocation of ICT Innovation and Production

Dependent Variables:	ICT Patents		Non-ICT Patents	
Model:	(1)	(2)	(3)	(4)
Emp Share in ICT × Before 1990	-2.469***	-0.3572	-2.099***	0.0417
	(0.3483)	(0.3348)	(0.4789)	(0.2579)
Emp Share in R&D × Before 1990	1.197***	0.1538	1.888***	0.1090
	(0.2404)	(0.1623)	(0.1659)	(0.0987)
Emp Share in ICT × Emp Share in R&D	13.65***	-6.463***	11.58***	-1.720*
× Before 1990	(1.752)	(2.328)	(1.969)	(0.9918)
Emp Share in ICT × After 1990	0.0474	0.1734*	-0.5885*	0.0899
	(0.3855)	(0.0910)	(0.3129)	(0.1260)
Emp Share in R&D × After 1990	1.446***	0.1529**	1.696***	0.2350***
	(0.2556)	(0.0600)	(0.2052)	(0.0675)
Emp Share in ICT × Emp Share in R&D	6.976***	1.341**	6.284***	0.2761
× After 1990	(0.8954)	(0.5218)	(1.478)	(0.7667)
Firm-Year	Yes	Yes	Yes	Yes
CZ-Year		Yes		Yes
Firm-CZ		Yes		Yes
Observations	1,200,983	255,573	2,769,075	893,019

Clustered (firm & CZ) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Region-Level Evidence

Spillovers from ICT to Non-ICT Innovation

CZs with higher pre-1990 ICT employment shares: greater post-shock ↑ in non-ICT patents

$$\text{Outcome}_{r,t} = \kappa \cdot \text{ Pre-1990 ICT Employment Share}_r \times \textbf{Level} \text{ of National ICT Patents}_t + \gamma_r + \gamma_t + \varepsilon_{r,t}$$

Dependent Variables:	Non-ICT Patents	Non-ICT Patents per capita
Model:	(1)	(2)
Pre-1990 ICT Employment Share$_r$× **Level** of National ICT Patents$_t$	0.2432***	3.13×10^{-5}*
	(0.0917)	(1.71×10^{-5})
Fixed-effects		
CZ	Yes	Yes
Year	Yes	Yes
Observations	20,938	20,938
R^2	0.94696	0.88179
Within R^2	0.10189	0.02474

Clustered (CZ) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

◂ Main Specification

Spillovers from ICT to Non-ICT Innovation after 1990

CZs with higher pre-1985 ICT employment shares: greater post-shock ↑ in non-ICT patents

$$\text{Outcome}_{r,t} = \kappa \cdot \text{ Pre-1985 ICT Employment Share}_r \times \text{Growth of National ICT Patents}_t + \gamma_r + \gamma_t + \varepsilon_{r,t}$$

Dependent Variables:	Non-ICT Patents	Non-ICT Patents per capita
Model:	(1)	(2)
Pre-1985 ICT Employment Share$_r \times$	437.9**	0.0405
Growth of National ICT Patents$_t$	(178.7)	(0.0330)
Fixed-effects		
CZ	Yes	Yes
Year	Yes	Yes
Observations	24,548	24,548
R^2	0.92056	0.83664
Within R^2	0.05451	0.00722

Clustered (CZ) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

◂ Main Specification

Spillovers from ICT to Non-ICT Innovation

CZs with higher pre-1985 ICT employment shares: greater post-shock ↑ in non-ICT patents

$$\text{Outcome}_{r,t} = \kappa \cdot \text{ Pre-1985 ICT Employment Share}_r \times \textbf{Level} \text{ of National ICT Patents}_t + \gamma_r + \gamma_t + \varepsilon_{r,t}$$

Dependent Variables:	Non-ICT Patents	Non-ICT Patents per capita
Model:	(1)	(2)
Pre-1985 ICT Employment Share$_r \times$	0.1683^{**}	1.56×10^{-5}
Level of National ICT Patents$_t$	(0.0687)	(1.27×10^{-5})
Fixed-effects		
CZ	Yes	Yes
Year	Yes	Yes
Observations	24,548	24,548
R^2	0.92056	0.83664
Within R^2	0.05451	0.00722

Clustered (CZ) standard-errors in parentheses

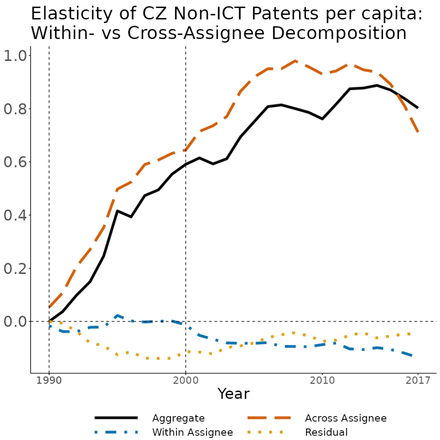
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Main Specification

Firm Decomposition of Non-ICT Patent Elasticity

Rise in non-ICT patent concentration: fully accounted for by compositional changes across firms

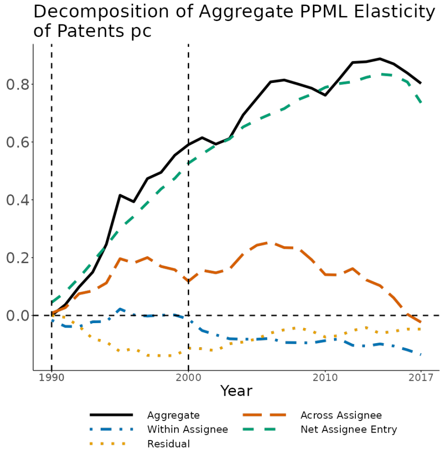
$$\alpha_{t^*} - \alpha_{1990} = \sum_{t=1991}^{t=t^*} \Delta\alpha_t = \sum_{t=1991}^{t=t^*} \Bigg[\underbrace{\sum_f \overline{\alpha}_{f,t} \Delta s_{f,t}}_{\text{changes across firms}} + \underbrace{\sum_f \overline{s}_{f,t} \Delta\alpha_{f,t}}_{\text{within-firm changes}} + \underbrace{\Delta\Big(\alpha_t - \sum_f s_{f,t}\alpha_{f,t}\Big)}_{\text{residual: changes in the colocation of firms}} \Bigg]$$



◂ Asymmetric Scale Effect

Firm Decomposition of Patent Elasticity

$$\alpha_{t^*} - \alpha_{1990} = \sum_{t=1991}^{t=t^*} \Delta\alpha_t = \sum_{t=1991}^{t=t^*} \left[\underbrace{\sum_f \overline{\alpha}_{f,t} \Delta s_{f,t}}_{\text{changes across firms}} + \underbrace{\sum_{f \in \mathcal{F}} s_{f,t} \alpha_{f,t}}_{\text{firm patent entry}} + \underbrace{\sum_f \overline{s}_{f,t} \Delta \alpha_{f,t}}_{\text{within-firm changes}} + \underbrace{\Delta\left(\alpha_t - \sum_f s_{f,t}\alpha_{f,t}\right)}_{\text{residual: changes in the colocation of firms}} \right]$$



◂ Main Within vs Cross Firm Decomposition

MODEL APPENDIX

Innovation and Technology Diffusion

- Two sectors (ICT and non-ICT);

$$\boxed{\textbf{Innovation (r)}} \xrightarrow{\textbf{diffusion}} \boxed{\text{Production (o)}} \xrightarrow{\text{trade}} \boxed{\text{Consumption (d)}}$$

Innovation and Technology Diffusion

- Two sectors (ICT and non-ICT);

$$\boxed{\textbf{Innovation (r)}} \xrightarrow{\textbf{diffusion}} \boxed{\text{Production (o)}} \xrightarrow{\text{trade}} \boxed{\text{Consumption (d)}}$$

- In each region and sector, **innovation** is the arrival of ideas:

$$\lambda^k_{r,t^*} = \underbrace{A_{r,t^*}}_{\substack{\text{fundamental} \\ \text{research} \\ \text{productivity} \\ \text{in region } r \\ \textbf{(function of} \\ \textbf{college ratio)}}} \cdot \underbrace{A^k_{t^*}}_{\substack{\text{sector-specific} \\ \text{national research} \\ \text{productivity} \\ \textbf{(ICT Shock} \\ \textbf{Aspect I)}}} \cdot \underbrace{T^k_{r,t^*}}_{\substack{\text{sector-specific} \\ \text{technology level} \\ \text{in region } r}} \cdot \underbrace{\left(L^{k,G}_{r,t^*}\right)^{\eta}}_{\substack{\text{number of} \\ \text{production} \\ \text{workers} \\ \text{(benefits of} \\ \textbf{colocation with} \\ \textbf{production})}} \cdot \underbrace{\left(L^{R}_{r,t^*}\right)^{\alpha}}_{\substack{\text{agglomeration} \\ \text{economies} \\ \text{in innovation} \\ \text{including } \textbf{spillovers} \\ \textbf{from ICT} \\ \textbf{to non-ICT}}} \cdot \underbrace{L^{k,R}_{r,t^*}}_{\substack{\text{number} \\ \text{of inventors} \\ \text{(captures the} \\ \text{impact of} \\ \text{the } \textbf{asymmetric} \\ \textbf{scale effect})}}$$

Innovation and Technology Diffusion

- Two sectors (ICT and non-ICT);

$$\boxed{\textbf{Innovation (r)}} \xrightarrow{\textbf{diffusion}} \boxed{\text{Production (o)}} \xrightarrow{\text{trade}} \boxed{\text{Consumption (d)}}$$

- In each region and sector, **innovation** is the arrival of ideas:

$$\lambda^k_{r,t^*} = \underbrace{A_{r,t^*}}_{\substack{\text{fundamental research productivity in region } r \\ \textbf{(function of college ratio)}}} \cdot \underbrace{A^k_{t^*}}_{\substack{\text{sector-specific national research productivity} \\ \textbf{(ICT Shock Aspect I)}}} \cdot \underbrace{T^k_{r,t^*}}_{\substack{\text{sector-specific technology level} \\ \text{in region } r}} \cdot \underbrace{\left(L^{k,G}_{r,t^*}\right)^\eta}_{\substack{\text{number of production workers} \\ \text{(benefits of } \textbf{colocation with production}\text{)}}} \cdot \underbrace{\left(L^R_{r,t^*}\right)^\alpha}_{\substack{\text{agglomeration economies in innovation} \\ \text{including } \textbf{spillovers from ICT to non-ICT}}} \cdot \underbrace{L^{k,R}_{r,t^*}}_{\substack{\text{number of inventors (captures the impact of} \\ \text{the } \textbf{asymmetric scale effect}\text{)}}}$$

- **Technology diffusion** is arrival of applications of each idea in different regions, depending on: $\Omega_{ro,t^*}(t-t^*) \equiv 1 - e^{-\delta_{ro,t^*}(t-t^*)}$
  - $\uparrow \delta_{t^*}$ captures reduced communication costs (**ICT Shock Aspect II**)

▸ Technical Details

▸ Worker Wages

Production

Production

$$\boxed{\text{Innovation (r)}} \xrightarrow{\text{diffusion}} \boxed{\textbf{Production (o)}} \xrightarrow{\text{trade}} \boxed{\text{Consumption (d)}}$$

- Each idea application produces a good with productivity z
  - Idea i: good $\nu \in [0, 1]$; random quality q
  - Application j of the idea: random applicability a

Production

Innovation (r) $\xrightarrow{\text{diffusion}}$ **Production (o)** $\xrightarrow{\text{trade}}$ Consumption (d)

- Each idea application produces a good with productivity z
  - Idea i: good $\nu \in [0, 1]$; random quality q
  - Application j of the idea: random applicability a

- Producers of each **individual good** ν employ production workers:

$$y_{o,t}(\nu) = z_{o,t}(\nu) \cdot L_{o,t}(\nu)$$

Production

Innovation (r) $\xrightarrow{\text{diffusion}}$ **Production (o)** $\xrightarrow{\text{trade}}$ Consumption (d)

- Each idea application produces a good with productivity z
  - Idea i: good $\nu \in [0, 1]$; random quality q
  - Application j of the idea: random applicability a

- Producers of each **individual good** ν employ production workers:

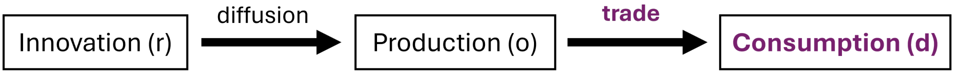
$$y_{o,t}(\nu) = z_{o,t}(\nu) \cdot L_{o,t}(\nu)$$

where $z_{o,t}(\nu)$ is the most productive idea for good ν available locally at time t:

$$z_{o,t}(\nu) = \max_i \{q_i a_{i,o,t}\} = \max_i \left\{ q_i \max_{j \in \mathcal{J}_{i,o,t}} \{a_j\} \right\}$$

▸ Productivity Distribution

Trade and Consumption



Trade and Consumption

$$\boxed{\text{Innovation (r)}} \xrightarrow{\text{diffusion}} \boxed{\text{Production (o)}} \xrightarrow{\textbf{trade}} \boxed{\textbf{Consumption (d)}}$$

- In each destination *d*, a final goods producer produces an **aggregate good**:

$$Y_{d,t} = \exp \int_0^1 \ln Y_{d,t}(\nu) d\nu$$

Trade and Consumption

$$\boxed{\text{Innovation (r)}} \xrightarrow{\text{diffusion}} \boxed{\text{Production (o)}} \xrightarrow{\textbf{trade}} \boxed{\textbf{Consumption (d)}}$$

- In each destination d, a final goods producer produces an **aggregate good**:

$$Y_{d,t} = \exp \int_0^1 \ln Y_{d,t}(\nu) d\nu$$

where each **individual good** ν is purchased from the lowest cost location:

$$c_{d,t}(\nu) = \min_o \left\{ \frac{\tau_{od,t} w_{o,t}}{z_{o,t}(\nu)} \right\}$$

Trade and Consumption

$$\boxed{\text{Innovation (r)}} \xrightarrow{\text{diffusion}} \boxed{\text{Production (o)}} \xrightarrow{\textbf{trade}} \boxed{\textbf{Consumption (d)}}$$

- In each destination d, a final goods producer produces an **aggregate good**:

$$Y_{d,t} = \exp \int_0^1 \ln Y_{d,t}(\nu) d\nu$$

where each **individual good** ν is purchased from the lowest cost location:

$$c_{d,t}(\nu) = \min_o \left\{ \frac{\tau_{od,t} w_{o,t}}{z_{o,t}(\nu)} \right\}$$

- Trade shares $\pi_{od,t}$ are the share of individual goods purchased by destination d that was produced in origin o

Equilibrium Trade and Technology Adoption Shares

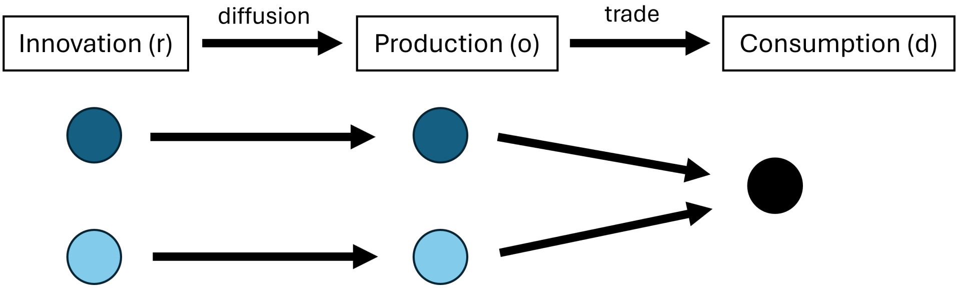
- Trade shares are given by:

$$\pi_{od,t} = \sum_{r=1}^{N} \pi_{rod,t} = \sum_{r=1}^{N} \int_{-\infty}^{t} \underbrace{\phi_{rd,t^*t}}_{\substack{\text{share of goods in } d \text{ at } t \\ \text{using ideas from } r \text{ at } t^* \\ \textbf{(idea market shares)}}} \cdot \underbrace{\varphi_{o|rd,t^*t}}_{\substack{\text{share of goods in } d \\ \text{produced in } o \text{ at } t \\ \text{given ideas from } r \text{ at } t^* \\ \text{(conditional } \textbf{idea} \\ \textbf{adoption shares}\text{)}}} dt^*$$

Equilibrium Trade and Technology Adoption Shares

- Trade shares are given by:

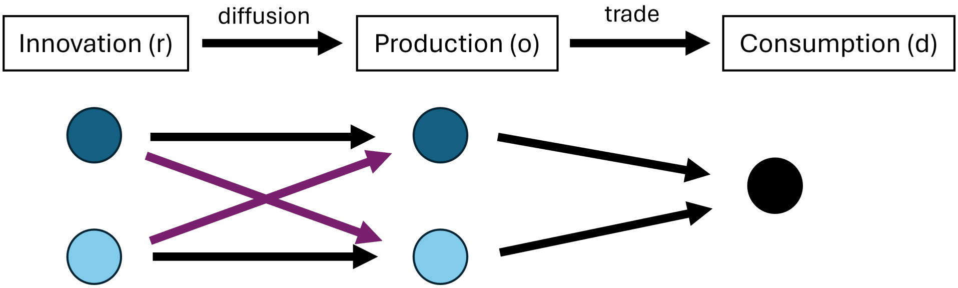
$$\pi_{od,t} = \sum_{r=1}^{N} \pi_{rod,t} = \sum_{r=1}^{N} \int_{-\infty}^{t} \underbrace{\phi_{rd,t^*t}}_{\substack{\text{share of goods in } d \text{ at } t \\ \text{using ideas from } r \text{ at } t^* \\ \textbf{(idea market shares)}}} \cdot \underbrace{\varphi_{o|rd,t^*t}}_{\substack{\text{share of goods in } d \\ \text{produced in } o \text{ at } t \\ \text{given ideas from } r \text{ at } t^* \\ \text{(conditional } \textbf{idea} \\ \textbf{adoption shares}\text{)}}} dt^*$$



Equilibrium Trade and Technology Adoption Shares

- Trade shares are given by:

$$\pi_{od,t} = \sum_{r=1}^{N} \pi_{rod,t} = \sum_{r=1}^{N} \int_{-\infty}^{t} \underbrace{\phi_{rd,t^*t}}_{\substack{\text{share of goods in } d \text{ at } t \\ \text{using ideas from } r \text{ at } t^* \\ \text{(idea market shares)}}} \cdot \underbrace{\varphi_{o|rd,t^*t}}_{\substack{\text{share of goods in } d \\ \text{produced in } o \text{ at } t \\ \text{given ideas from } r \text{ at } t^* \\ \text{(conditional idea} \\ \text{adoption shares)}}} dt^*$$



Equilibrium Trade and Technology Adoption Shares

- Trade shares are given by:

$$\pi_{od,t} = \sum_{r=1}^{N} \pi_{rod,t} = \sum_{r=1}^{N} \int_{-\infty}^{t} \underbrace{\phi_{rd,t^*t}}_{\substack{\text{share of goods in } d \text{ at } t \\ \text{using ideas from } r \text{ at } t^* \\ \text{(idea market shares)}}} \cdot \underbrace{\varphi_{o|rd,t^*t}}_{\substack{\text{share of goods in } d \\ \text{produced in } o \text{ at } t \\ \text{given ideas from } r \text{ at } t^* \\ \text{(conditional idea} \\ \text{adoption shares)}}} dt^*$$

$$= \sum_{r=1}^{N} \int_{-\infty}^{t} \frac{\Phi_{rd,t^*t}^{1-\rho} \lambda_{r,t^*}}{\sum_{r'} \int_{-\infty}^{t} \Phi_{r'd,t't}^{1-\rho} \lambda_{r',t'} dt'} \cdot \frac{\left[1 - e^{-\delta_{ro,t^*}(t-t^*)}\right] \left(w_{o,t}\tau_{od,t}\right)^{-\frac{\theta}{1-\rho}}}{\sum_{o'} \left[1 - e^{-\delta_{ro',t^*}(t-t^*)}\right] \left(w_{o',t}\tau_{o'd,t}\right)^{-\frac{\theta}{1-\rho}}} dt^*$$

where Φ_{rd,t^*t} is the ideas' market access:

$$\Phi_{rd,t^*t} = \sum_{o'} \left(1 - e^{-\delta_{ro',t^*}(t-t^*)}\right) \left(w_{o',t}\tau_{o'd,t}\right)^{-\frac{\theta}{1-\rho}}$$

The Asymmetric Scale Effect

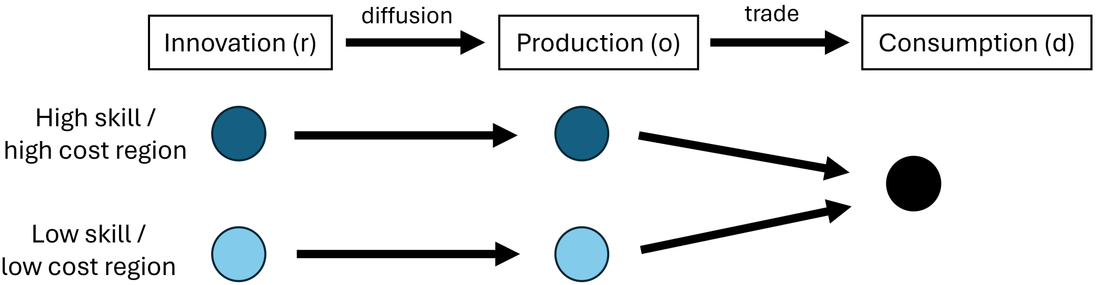
- Idea market access:

$$\Phi_{rd,t^*t} \equiv \sum_o \varphi_{o|rd,t^*t} = \sum_o \left(1 - e^{-\boldsymbol{\delta_{ro,t^*}}(t-t^*)}\right)\left(w_{o,t}\tau_{od,t}\right)^{-\frac{\theta}{1-\rho}}$$

The Asymmetric Scale Effect

- Idea market access:

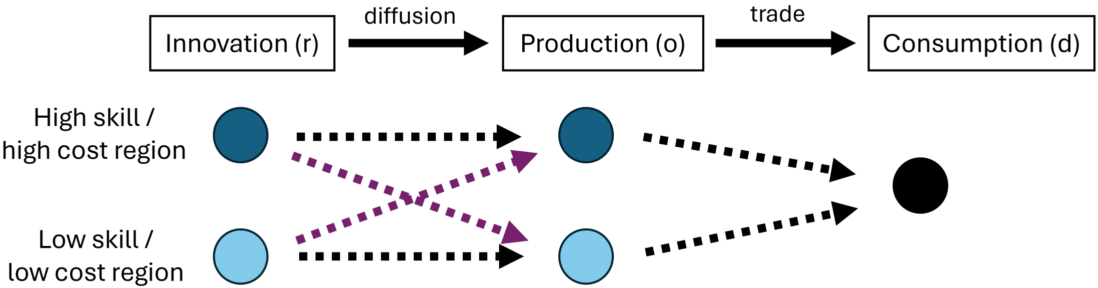
$$\Phi_{rd,t^*t} \equiv \sum_o \varphi_{o|rd,t^*t} = \sum_o \left(1 - e^{-\delta_{ro,t^*}(t-t^*)}\right)(w_{o,t}\tau_{od,t})^{-\frac{\theta}{1-\rho}}$$



The Asymmetric Scale Effect

- Idea market access:

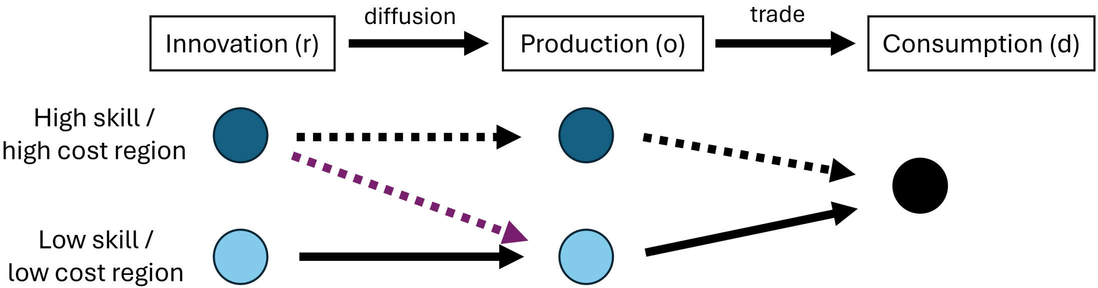
$$\Phi_{rd,t^*t} \equiv \sum_o \varphi_{o|rd,t^*t} = \sum_o \left(1 - e^{-\delta_{ro,t^*}(t-t^*)}\right)\left(w_{o,t}\tau_{od,t}\right)^{-\frac{\theta}{1-\rho}}$$



The Asymmetric Scale Effect

- Idea market access:

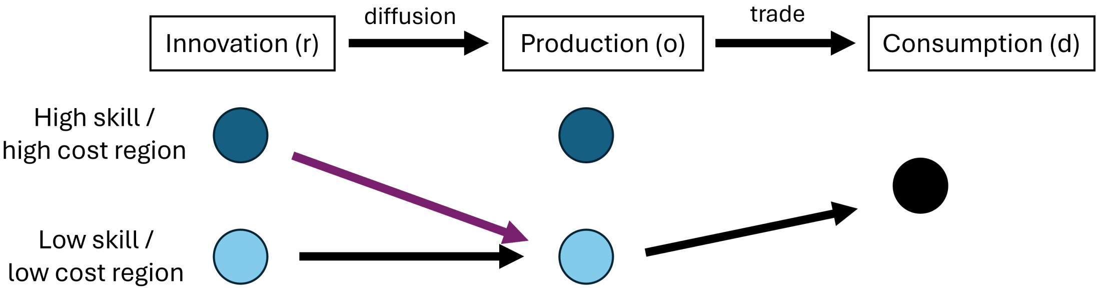
$$\Phi_{rd,t^*t} \equiv \sum_o \varphi_{o|rd,t^*t} = \sum_o \left(1 - e^{-\delta_{ro,t^*}(t-t^*)}\right)\left(w_{o,t}\tau_{od,t}\right)^{-\frac{\theta}{1-\rho}}$$



The Asymmetric Scale Effect

- Idea market access:

$$\Phi_{rd,t^*t} \equiv \sum_{o} \varphi_{o|rd,t^*t} = \sum_{o} \left(1 - e^{-\delta_{ro,t^*}(t-t^*)}\right) \left(w_{o,t}\tau_{od,t}\right)^{-\frac{\theta}{1-\rho}}$$

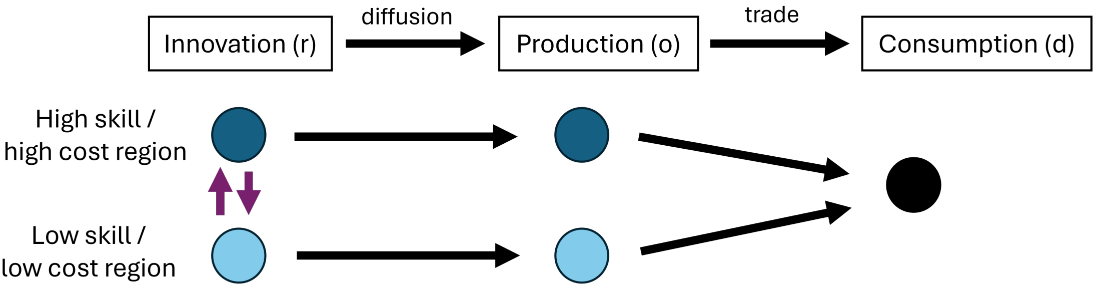


The Asymmetric Scale Effect

- Cannot be obtained when diffusion:
  - Occurs at an aggregate level (Desmet et al 2018), or;
  - Is microfounded but independent from innovation (Buera and Oberfield 2020)

The Asymmetric Scale Effect

- Cannot be obtained when diffusion:
  - Occurs at an aggregate level (Desmet et al 2018), or;
  - Is microfounded but independent from innovation (Buera and Oberfield 2020)



▸ Colocation between Innovation and Production

Innovation and Production Worker Wages

- In each region and sector, firms pay **innovation workers** their expected return from research and own their ideas: ▸ Details

$$w_{r,t^*}^{k,R} = \frac{\lambda_{r,t^*}^{k}}{L_{r,t^*}^{k,R}} \check{V}_{r,t^*}^{k}$$

◂ Innovation Levels

Innovation and Production Worker Wages

- In each region and sector, firms pay **innovation workers** their expected return from research and own their ideas: ▸ Details

$$w^{k,R}_{r,t^*} = \frac{\lambda^k_{r,t^*}}{L^{k,R}_{r,t^*}} \check{V}^k_{r,t^*}$$

◂ Innovation Levels

- Firms engage in Bertrand competition $\implies$ profits from production ▸ Details

Innovation and Production Worker Wages

- In each region and sector, firms pay **innovation workers** their expected return from research and own their ideas: Details

$$w^{k,R}_{r,t^*} = \frac{\lambda^k_{r,t^*}}{L^{k,R}_{r,t^*}} \check{V}^k_{r,t^*}$$

Innovation Levels

- Firms engage in Bertrand competition $\implies$ profits from production Details

- **Production worker wages** come from the market clearing condition Details

Innovation and Technology Diffusion

- In each region r, the number of ideas with quality greater than q discovered by time t is:

$$\lambda^{Q}_{r,t}(q) = q^{-\theta} \int_0^t \lambda_{r,t^*} dt^*, \tag{1}$$

  where λ_{r,t^*} is the arrival rate of ideas with $q > 1$ at time t^*

  - λ_{r,t^*} depends on the **one-time increase in ICT research productivity nationwide**, the benefits of colocation, innovation spillovers, and number of innovation workers

- Once an idea is discovered in region r at time t^*, the number of applications of the idea in region o and time t above a is:

$$\lambda^{A}_{ro,t^* t}(a) = a^{-\sigma} \cdot \Omega_{ro,t^*}(t - t^*) \cdot \Gamma \tag{2}$$

  - Assumption 1: $\Omega_{ro,t^*}(t - t^*) = 1 - e^{-\delta_{ro,t^*}(t-t^*)}$
  - δ_{t^*} captures **reduced communication costs**

◂ Main Model

Goods Productivity Distribution

- The **joint productivity distribution** across regions is multivariate Frechet:

$$\mathbb{P}\left[Z_{1,t} \leq z_1, \ldots, Z_{N,t} \leq z_N\right] = \exp\left[-\sum_{l=1}^{N} \int_{-\infty}^{t} \left[\sum_{o=1}^{N} \left(1 - e^{-\delta_{lo}(t-t^*)}\right) z_o^{-\frac{\theta}{1-\rho}}\right]^{1-\rho} \lambda_{l,t^*} dt^*\right]$$

  with correlation parameter $\rho = 1 - \frac{\theta}{\sigma}$.

- The **marginal productivity distribution** in each region is Frechet:

$$\mathbb{P}\left[Z_{o,t} \leq z_o\right] = \exp\left[-T_{o,t} z_o^{-\theta}\right]$$

  with shape parameter $\theta > 0$ and scale parameter:

$$T_{o,t} = \sum_{l=1}^{N} T_{lo,t} = \sum_{l=1}^{N} \int_{-\infty}^{t} \underbrace{\left(1 - e^{-\delta_{lo}(t-t^*)}\right)^{1-\rho}}_{\text{exponential diffusion}} \cdot \underbrace{\lambda_{l,t^*}}_{\text{innovation}} dt^*$$

◂ Production

Trade and Technology Adoption

- The **idea market shares** are:

$$\phi_{rd,t^*t} = \frac{\Phi^{1-\rho}_{rd,t^*t}\lambda_{r,t^*}}{\sum_{r'}\int_{-\infty}^{t}\Phi^{1-\rho}_{r'd,t't}\lambda_{r',t'}\,dt'}, \quad \rho < 1 \tag{3}$$

  where I define **idea market access** as:

$$\Phi_{rd,t^*t} \equiv \sum_{o}\left(1 - e^{-\delta_{ro,t^*}(t-t^*)}\right)\left(w_{o,t}\tau_{od,t}\right)^{-\frac{\theta}{1-\rho}} = \sum_{o}\varphi_{o|rd,t^*t} \tag{4}$$

- **Corollary 2 (Asymmetric Scale Effect):**

  When diffusion speeds are symmetric and trade costs identical across region-pairs,

$$\frac{\partial\Phi_{rd,t^*t}}{\partial\delta_{rr',t^*}} - \frac{\partial\Phi_{r'd,t^*t}}{\partial\delta_{rr',t^*}} = \delta_{rr',t^*}e^{-\delta_{rr',t^*}(t-t^*)}\left[\left(w_{r',t}\tau_{r'd,t}\right)^{-\theta} - \left(w_{r,t}\tau_{rd,t}\right)^{-\theta}\right] > 0 \quad \text{if} \quad w_{r,t} > w_{r',t}.$$

Colocation between Innovation and Production

- Conditional idea adoption shares:

$$\varphi_{o|rd,t^*t} = \frac{\left[1 - e^{-\delta_{ro,t^*}(t-t^*)}\right] \left(w_{o,t}\tau_{od,t}\right)^{-\frac{\theta}{1-\rho}}}{\sum_{o'} \left[1 - e^{-\delta_{ro',t^*}(t-t^*)}\right] \left(w_{o',t}\tau_{o'd,t}\right)^{-\frac{\theta}{1-\rho}}}$$

- Unconditional idea adoption shares: $\varphi_{ro,t^*t} = \sum_d \varphi_{o|rd,t^*t}$

- **Corollary 1**: The degree of **colocation between innovation and production** is:

$$\frac{\varphi_{rr,t^*t}}{\varphi_{ro,t^*t}} = \underbrace{\frac{1}{1 - e^{-\delta_{ro,t^*}(t-t^*)}}}_{\substack{\text{technology} \\ \text{diffusion}}} \cdot \underbrace{\left(\frac{w_{r,t}}{w_{o,t}}\right)^{-\frac{\theta}{1-\rho}}}_{\substack{\text{cost} \\ \text{competitiveness}}} \cdot \underbrace{\left(\frac{\sum_d \tau_{rd,t}}{\sum_d \tau_{od,t}}\right)^{-\frac{\theta}{1-\rho}}}_{\substack{\text{accessibility of} \\ \text{destination markets}}}$$

◂ Asymmetric Scale Effect

Bertrand Competition and Profits from Sales

- In each region and sector, there is a unit continuum of firms. Firms hire inventors to produce research and own their ideas, so each firm is a collection of ideas.
- Firms engage in Bertrand competition: the lowest cost producer for each good charges the second lowest cost and claims its entire market
  - Lemma 4: The markup for each good is drawn from a time- and region-invariant Pareto distribution $G^{(2)/(1)}(m)$
- On aggregate, profits earned in each destination is a constant share of local income

$$\Pi_{d,t} = X_{d,t} \int_0^1 1 - \frac{1}{m(\nu)} d\nu = X_{d,t} \int_1^\infty 1 - \frac{1}{m(\nu)} dG^{(2)/(1)}(m) = \frac{X_{d,t}}{1+\theta} \tag{5}$$

◂ Innovation and Production Worker Wages

Allocation of Profits from Sales and Innovation Worker Wages

- Assumption 2(i): all profits from sales are allocated to innovation

  $\implies$ The expected value of an idea:

$$\check{V}_{r,t^*} = \int_{t^*}^{\infty} e^{-\zeta(t-t^*)} \sum_{d=1}^{N} \underbrace{\frac{\phi_{rd,t^*t}}{\lambda_{r,t^*}}}_{\substack{\text{share of profits earned}\\ \text{in region } d \text{ at time } t\\ \text{by an idea discovered}\\ \text{in region } r \text{ at time } t^*}} \cdot \underbrace{\frac{X_{d,t}}{1+\theta}}_{\substack{\text{profits earned}\\ \text{in region } d\\ \text{at time } t\\ \text{by all ideas}}} \cdot \underbrace{\frac{P_{rt^*}}{P_{rt}}}_{\substack{\text{accounting for}\\ \text{changes in}\\ \text{purchasing power}\\ \text{over time}}} dt \tag{6}$$

- Assumption 2(ii): firms reinvest their profits in risk-free assets, pay innovation workers their expected return from research

  $\implies$ wages from research:

$$w_{r,t^*}^{k,R} = \frac{\lambda_{r,t^*}^{k}}{L_{r,t^*}^{k,R}} \check{V}_{r,t^*}^{k} \tag{7}$$

Innovation and Production Worker Wages

Consumption and Market Clearing

Pins down production worker wages

- Workers have Cobb-Douglas preferences over local final goods,
  ι is the expenditure share on the final good in the ICT sector

- Market clearing at each time t:

$$\frac{1+\theta}{\theta} w_{o,t}^{k} L_{o,t}^{k} = \sum_{d} \pi_{od,t}^{k} \iota^{k} \left[\sum_{s} \left(w_{d,t}^{s} L_{d,t}^{s} + \sum_{r} \varphi_{dr,t}^{s} \frac{1}{\theta} w_{r,t}^{s} L_{r,t}^{s} \right) \right] \quad (8)$$

- Sectoral price index:

$$P_{d,t}^{k} = \gamma \left[\sum_{r'=1}^{N} \int_{-\infty}^{t} {\Phi_{r'd,t^{*}t}^{k}}^{1-\rho} \lambda_{r',t^{*}}^{k} dt^{*} \right]^{-\frac{1}{\theta}} \quad (9)$$

◂ Innovation and Production Worker Wages

Dynamic Worker Mobility

- Assumption 3: A Poisson process with rate 1 governs when **all** workers can move

- Individual worker mobility problem at time *t*:

$$v_{d,t}^{k,h} = \max_{o,s,n} \quad \mathbb{E}_t \left(\int_t^{t'} \frac{w_{d,\check{t}}^{k,h}}{P_{d,\check{t}}} d\check{t} \right) + \frac{1}{1+\zeta} \mathbb{E}_t \left(\mathbb{E}_\epsilon \left[v_{o,t'}^{s,n} \right] \right) - \kappa_{do,t}^{ks,hn} + \epsilon_{o,t}^{s,n} \tag{10}$$

where $\epsilon_{o,t}^{s,n}$ is an individual-specific idiosyncratic shock:

$$\check{F}\left(\left\{ \epsilon_{o,t}^{s,n} \right\}_{o=1,\ldots,N}^{s=\{\text{ICT},\text{non-ICT}\},n=\{G,R\}} \right) = \exp \left\{ - \left[\sum_o \sum_s \left(\sum_n \exp\left(-\epsilon_{o,t}^{s,n} \right)^{\frac{\Upsilon}{\upsilon}} \right)^{\upsilon} \right] \right\}$$

Dynamic Worker Mobility

- Assumption 3: A Poisson process with rate 1 governs when **all** workers can move

- Individual worker mobility problem at time t:

$$v_{d,t}^{k,h} = \max_{o,s,n} \quad \mathbb{E}_t\left(\int_t^{t'} \frac{w_{d,\check{t}}^{k,h}}{P_{d,\check{t}}} d\check{t}\right) + \frac{1}{1+\zeta}\mathbb{E}_t\left(\mathbb{E}_\epsilon\left[v_{o,t'}^{s,n}\right]\right) - \kappa_{do,t}^{ks,hn} + \epsilon_{o,t}^{s,n} \tag{10}$$

where $\epsilon_{o,t}^{s,n}$ is an individual-specific idiosyncratic shock:

$$\check{F}\left(\left\{\epsilon_{o,t}^{s,n}\right\}_{o=1,\ldots,N}^{s=\{\text{ICT,non-ICT}\},n=\{G,R\}}\right) = \exp\left\{-\left[\sum_o\sum_s\left(\sum_n \exp\left(-\epsilon_{o,t}^{s,n}\right)^{\frac{\Upsilon}{\upsilon}}\right)^{\upsilon}\right]\right\}$$

- Expected worker value:

$$V_{d,t}^{k,h} \equiv \mathbb{E}_\epsilon\left[v_{d,t}^{k,h}\right] = \int_t^{t'} \frac{w_{d,\check{t}}^{k,h}}{P_{d,\check{t}}} d\check{t} + \frac{1}{\Upsilon}\log\left[\sum_o\sum_s\left(\sum_n \exp\left(\frac{1}{1+\zeta}V_{o,t'}^{s,n} - \kappa_{do,t}^{ks,hn}\right)^{\frac{\Upsilon}{\upsilon}}\right)^{\upsilon}\right] \tag{11}$$

◂ Spatial Direction of Innovation

Dynamic Worker Mobility

- Aggregate mobility shares:

$$\mu^{ks,hn}_{do,t} \equiv \mu^{ks,hn}_{do,t} | \mu^{ks}_{do,t} \cdot \mu^{ks}_{do,t}$$

$$= \underbrace{\frac{\exp\left(\frac{1}{1+\zeta} V^{s,n}_{o,t'} - \kappa^{ks,hn}_{do,t}\right)^{\frac{\Upsilon}{\upsilon}}}{\sum_{n'} \exp\left(\frac{1}{1+\zeta} V^{s,n'}_{o,t'} - \kappa^{ks,hn'}_{do,t}\right)^{\frac{\Upsilon}{\upsilon}}}}_{\text{switching between production and research}} \cdot \underbrace{\frac{\left[\sum_{n'} \exp\left(\frac{1}{1+\zeta} V^{s,n'}_{o,t'} - \kappa^{ks,hn'}_{do,t}\right)^{\frac{\Upsilon}{\upsilon}}\right]^{\upsilon}}{\sum_{o'} \sum_{s'} \left[\sum_{n'} \exp\left(\frac{1}{1+\zeta} V^{s',n'}_{o',t'} - \kappa^{ks',hn'}_{do',t}\right)^{\frac{\Upsilon}{\upsilon}}\right]^{\upsilon}}}_{\text{mobility across regions and sectors}} \tag{12}$$

- Evolution of worker population

$$L^{s,n}_{o,t'} = \sum_h \sum_k \sum_d \mu^{ks,hn}_{do,t'} L^{k,h}_{d,t} \tag{13}$$

◂ Spatial Direction of Innovation

AGGREGATE CONSEQUENCES OF THE ICT SHOCK

Transition Path

Fundamentals → Evolution of the **geography of innovation** (**Proposition 3**)

- Assumption 4: The economy is on a balanced growth path from time $-\infty$ to 0
- **Initial conditions**: technology levels T_0; distribution of workers L_0
- **Time-varying fundamentals**: research productivities A; diffusion speeds δ; trade costs τ; migration costs κ
- **Parameters**: elasticities, sector share and discount rate $\{\theta, \sigma, \upsilon, \Upsilon, \alpha, \eta, \iota, \zeta\}$
- **Endogenous variables**:
  - Innovation levels and technology levels
  - Trade and technology adoption shares
  - Profits from sales, expected value of individual ideas, and innovation worker wages
  - Price indices, market clearing condition, and production worker wages
  - Worker mobility shares and distribution of workers

◂ Conclusion

Welfare Impacts of a Shock to Fundamentals

- Welfare as the compensating variation in consumption (Caliendo et al 2019):

$$V_{d,0}^{k,h\prime} = V_{d,0}^{k,h} + \sum_{t \in \mathcal{T}_0^{\infty}} \left(\frac{1}{1+\zeta} \right)^t \log \chi_d^{k,h}$$

- **Proposition 4**: The **welfare** impact of a shock to fundamentals is:

$$\log\left(\chi_d^{k,h}\right) = \sum_{t \in \mathcal{T}_0^{\infty}} \left(\frac{1}{1+\zeta} \right)^t \log \left(\underbrace{\frac{\widehat{w}_{d,t}^{k,h}}{\widehat{P}_{d,t}}}_{\substack{\text{change in} \\ \text{future} \\ \text{detrended} \\ \text{real wages}}} \underbrace{\frac{1}{\left(\widehat{\mu_{dd,t}^{kk}}\right)^{1/\Upsilon} \left(\widehat{\mu_{dd,t}^{kk,hh} | \mu_{dd,t}^{kk}}\right)^{\upsilon/\Upsilon}}}_{\text{change in option value of migration}} \right) + \underbrace{\frac{1}{\theta} \sum_k \iota^k \left(g^{k\prime} - g^k \right)}_{\text{growth effects}}$$

Conclusion