

# THE GEOGRAPHY OF INVENTORS AND LOCAL KNOWLEDGE SPILLOVERS IN R&D

Brian C. Fujii  
U.S. Census Bureau<sup>1</sup>

---

<sup>1</sup>Any opinions and conclusions expressed herein are those of the authors and do not represent the views of the U.S. Census Bureau.

# INTRODUCTION

- Research and Development (R&D)  $\Rightarrow$  Aggregate innovation  $\Rightarrow$  LR Growth
- R&D concentrates in space. Top 3 West German cities:

Inventors in <i>Mech. Engineer.</i>	>	Workers
29.86% inventors		17.39%
- Understudied: causes/consequences of agglomeration economies in R&D

## Local Knowledge Spillovers in R&D

### Research questions:

1. Evidence on local knowledge spillovers in R&D?
2. Quantitative importance of spillovers when implementing R&D policies?

# INTRODUCTION

- Research and Development (R&D)  $\Rightarrow$  Aggregate innovation  $\Rightarrow$  LR Growth
- R&D concentrates in space. Top 3 West German cities:

Inventors in <i>Mech. Engineer.</i>	>	Workers
29.86% inventors		17.39%

- Understudied: causes/consequences of agglomeration economies in R&D

## Local Knowledge Spillovers in R&D

### Research questions:

1. Evidence on local knowledge spillovers in R&D?
2. Quantitative importance of spillovers when implementing R&D policies?

# INTRODUCTION

- Research and Development (R&D)  $\Rightarrow$  Aggregate innovation  $\Rightarrow$  LR Growth
- R&D concentrates in space. Top 3 West German cities:

Inventors in <i>Mech. Engineer.</i>	>	Workers
29.86% inventors		17.39%

- Understudied: causes/consequences of agglomeration economies in R&D

## Local Knowledge Spillovers in R&D

### Research questions:

1. Evidence on local knowledge spillovers in R&D?
2. Quantitative importance of spillovers when implementing R&D policies?

# INTRODUCTION

- Research and Development (R&D)  $\Rightarrow$  Aggregate innovation  $\Rightarrow$  LR Growth
- R&D concentrates in space. Top 3 West German cities:

Inventors in <i>Mech. Engineer.</i>	>	Workers
29.86% inventors		17.39%

- Understudied: causes/consequences of agglomeration economies in R&D

Local Knowledge Spillovers in R&D

## Research questions:

1. Evidence on local knowledge spillovers in R&D?
2. Quantitative importance of spillovers when implementing R&D policies?

# INTRODUCTION

- Research and Development (R&D)  $\Rightarrow$  Aggregate innovation  $\Rightarrow$  LR Growth
- R&D concentrates in space. Top 3 West German cities:

Inventors in <i>Mech. Engineer.</i>	>	Workers
29.86% inventors		17.39%

- Understudied: causes/consequences of agglomeration economies in R&D

Local Knowledge Spillovers in R&D

## Research questions:

1. Evidence on local knowledge spillovers in R&D?
2. Quantitative importance of spillovers when implementing R&D policies?

# INTRODUCTION

- Research and Development (R&D)  $\Rightarrow$  Aggregate innovation  $\Rightarrow$  LR Growth
- R&D concentrates in space. Top 3 West German cities:

Inventors in <i>Mech. Engineer.</i>	>	Workers
29.86% inventors		17.39%

- Understudied: causes/consequences of agglomeration economies in R&D

## Local Knowledge Spillovers in R&D

### Research questions:

1. Evidence on local knowledge spillovers in R&D?
2. Quantitative importance of spillovers when implementing R&D policies?

# INTRODUCTION

- Research and Development (R&D)  $\Rightarrow$  Aggregate innovation  $\Rightarrow$  LR Growth
- R&D concentrates in space. Top 3 West German cities:

Inventors in <i>Mech. Engineer.</i>	>	Workers
29.86% inventors		17.39%

- Understudied: causes/consequences of agglomeration economies in R&D

## Local Knowledge Spillovers in R&D

### Research questions:

1. Evidence on local knowledge spillovers in R&D?
2. Quantitative importance of spillovers when implementing R&D policies?



# SUMMARY

## Empirics

- Data: Matched administrative panel on German inventors, 1980-2014
  - ▶ Inventors' **technological clusters** and patents' **citation counts**
- Local Knowledge Spillovers in R&D:
  - ▶ Reunification of Germany in 1990  $\Rightarrow$  arrival of East German inventors in West Germany
    - ▶ Quasi-exogenous variation across West German clusters
  - ▶  $\uparrow$  10% cluster size  $\Rightarrow$   $\uparrow$  4% inventor productivity gains

# SUMMARY

## Empirics

- Data: Matched administrative panel on German inventors, 1980-2014
  - ▶ Inventors' **technological clusters** and patents' **citation counts**
- Local Knowledge Spillovers in R&D:
  - ▶ Reunification of Germany in 1990  $\Rightarrow$  arrival of East German inventors in West Germany
    - ▶ Quasi-exogenous variation across West German clusters
  - ▶  $\uparrow$  10% cluster size  $\Rightarrow$   $\uparrow$  4% inventor productivity gains

# SUMMARY

## Empirics

- Data: Matched administrative panel on German inventors, 1980-2014
  - ▶ Inventors' **technological clusters** and patents' **citation counts**
- Local Knowledge Spillovers in R&D:
  - ▶ Reunification of Germany in 1990  $\Rightarrow$  arrival of East German inventors in West Germany
    - ▶ Quasi-exogenous variation across West German clusters
  - ▶  $\uparrow$  10% cluster size  $\Rightarrow$   $\uparrow$  4% inventor productivity gains

# SUMMARY

## Spatial model of innovation

- Tradable intermediate inputs with endogenous quality
  1. Quality determined by firm inventors' R&D
  2. R&D subject to spillovers estimated from the data

## R&D policies

1. Inventor mobility matters
  - ▶ Complementarity between spillovers and ↓ inventor migration costs
2. R&D subsidies matter
  - ▶ Small effect of 25% subsidy from *2020 German R&D Tax Allowance Act*
  - ▶ Optimal R&D subsidies are place-based

# SUMMARY

## Spatial model of innovation

- Tradable intermediate inputs with endogenous quality
  1. Quality determined by firm inventors' R&D
  2. R&D subject to spillovers estimated from the data

## R&D policies

1. Inventor mobility matters
  - ▶ Complementarity between spillovers and ↓ inventor migration costs
2. R&D subsidies matter
  - ▶ Small effect of 25% subsidy from *2020 German R&D Tax Allowance Act*
  - ▶ Optimal R&D subsidies are place-based

# SUMMARY

## Spatial model of innovation

- Tradable intermediate inputs with endogenous quality
  1. Quality determined by firm inventors' R&D
  2. R&D subject to spillovers estimated from the data

## R&D policies

1. Inventor mobility matters
  - ▶ Complementarity between spillovers and ↓ inventor migration costs
2. R&D subsidies matter
  - ▶ Small effect of 25% subsidy from *2020 German R&D Tax Allowance Act*
  - ▶ Optimal R&D subsidies are place-based

# SUMMARY

## Spatial model of innovation

- Tradable intermediate inputs with endogenous quality
  1. Quality determined by firm inventors' R&D
  2. R&D subject to spillovers estimated from the data

## R&D policies

1. Inventor mobility matters
  - ▶ Complementarity between spillovers and ↓ inventor migration costs
2. R&D subsidies matter
  - ▶ Small effect of 25% subsidy from *2020 German R&D Tax Allowance Act*
  - ▶ Optimal R&D subsidies are place-based

# LITERATURE

**Local knowledge spillovers (Empirical):** Griliches (1991); Jaffe et al. (1993); Audretsch and Feldman (1996); Jaffe et al. (2000); Thompson (2006); Carlino et al. (2007); Combes et al. (2010); Greenstone et al. (2010); Bloom et al. (2013); Kerr and Kominers (2015); Kantor and Whalley (2019); Moretti (2021); Gruber et al. (2022)

⇒ Contribution: New evidence on these spillovers

## Innovation and knowledge spillovers (Quantitative)

- *Urban:* Eaton and Eckstein (1997); Glaeser (1999); Black and Henderson (1999); Kelly and Hageman (1999); Duranton and Puga (2001); Duranton (2007); Roca and Puga (2017); Duranton and Puga (2019); Davis and Dingel (2019)
- *Trade:* Ramondo et al. (2016); Hallak and Sivadasan (2013); Atkeson and Burstein (2010); Melitz (2003); Eaton and Kortum (2002); Krugman (1980); Akcigit et al. (2021)
- *Spatial:* Desmet and Rossi-Hansberg (2014); Desmet et al. (2018); Nagy et al. (2016); Mestieri et al. (2021)

⇒ Contribution: Migration costs + Spillovers ⇒ Geography of inventors matters in the aggregate

## Labor mobility and innovation + productivity + growth

- *Empirical:* Kerr (2010); Borjas and Doran (2012); Burchardi and Hassan (2013); Moser et al. (2014); Peri et al. (2015); Bosetti et al. (2015); Kerr and Kominers (2015); Kerr et al. (2017); Bahar et al. (2020); Burchardi et al. (2020); Bernstein et al. (2022); Chattergoon and Kerr (2022)
- *Quantitative:* Monras (2018); Bryan and Morten (2019); Peters (2019); Arkolakis et al. (2020); Pellegrina and Sotelo (2021); Prato (2021)

⇒ Contribution: Quantification of internal mobility of inventors on productivity



# EMPIRICS

1. Data
2. Local Knowledge Spillovers in R&D
  - ⇒ The Reunification of Germany
  - ⇒ IV

# EMPIRICS

1. Data
2. Local Knowledge Spillovers in R&D
  - ⇒ The Reunification of Germany
  - ⇒ IV

# DATA

## Final dataset Inventor/year panel

- *Source:* IAB-FDZ's Linked Inventor Biography (INV-BIO)
- *Agents:* West German inventors, 1980-2014
- *Inventor productivity:* # inventor's new patents' citations
- *Location:* 104 labor markets      inventor's establishment
- *Patent type:* 5 technological areas
- *Cluster size:* # inventors in techn. area/labor market pair

» Occupation of inventors

» Industry of firms

» Technological area of patents

» Top 10: Electric. engineer.

» Top 10: Instruments

» Top 10: Chemistry

» Top 10: Mechanic. engineer.

# EMPIRICS

1. Data
2. Local Knowledge Spillovers in R&D
  - ⇒ The Reunification of Germany
  - ⇒ IV

# LOCAL KNOWLEDGE SPILLOVERS IN R&D

## Baseline specification

$$\log \left( Z_{da,t}^{i\omega} \right) = \iota_{d,t} + \iota_{a,t} + \iota_{da} + \iota_{\omega} + \iota_i + \beta \log \left( R_{da,t} \right) + \epsilon_{da,t}^{i\omega}$$

where

- $Z_{da,t}^{i\omega}$  : # of inventor  $i$ 's *new patents*' 5-year forward citations in period  $t$
- $R_{da,t}$  : # of inventors in cluster  $(d, a)$  in period  $t$

## Local Knowledge spillovers in R&D

- Ha:  $\beta > 0$

## FEs

- $\iota_{d,t}$  : amenities + labor market shocks
- $\iota_{a,t}$  : technological change
- $\iota_{da}$  : cluster-specific productivity
- $\iota_{\omega}$  : firm-specific productivity
- $\iota_i$  : sorting from inventor-specific productivity

# LOCAL KNOWLEDGE SPILLOVERS IN R&D

## Baseline specification

$$\log \left( Z_{da,t}^{i\omega} \right) = \iota_{d,t} + \iota_{a,t} + \iota_{da} + \iota_{\omega} + \iota_i + \beta \log \left( R_{da,t} \right) + \epsilon_{da,t}^{i\omega}$$

where

- $Z_{da,t}^{i\omega}$  : # of inventor  $i$ 's *new patents*' 5-year forward citations in period  $t$
- $R_{da,t}$  : # of inventors in cluster  $(d, a)$  in period  $t$

## Local Knowledge spillovers in R&D

- Ha:  $\beta > 0$

## FEs

- $\iota_{d,t}$  : amenities + labor market shocks
- $\iota_{a,t}$  : technological change
- $\iota_{da}$  : cluster-specific productivity
- $\iota_{\omega}$  : firm-specific productivity
- $\iota_i$  : sorting from inventor-specific productivity

# LOCAL KNOWLEDGE SPILLOVERS IN R&D

## Baseline specification

$$\log \left( Z_{da,t}^{i\omega} \right) = \iota_{d,t} + \iota_{a,t} + \iota_{da} + \iota_{\omega} + \iota_i + \beta \log \left( R_{da,t} \right) + \epsilon_{da,t}^{i\omega}$$

where

- $Z_{da,t}^{i\omega}$  : # of inventor  $i$ 's *new patents*' 5-year forward citations in period  $t$
- $R_{da,t}$  : # of inventors in cluster  $(d, a)$  in period  $t$

## Local Knowledge spillovers in R&D

- Ha:  $\beta > 0$

## FEs

- $\iota_{d,t}$  : amenities + labor market shocks
- $\iota_{a,t}$  : technological change
- $\iota_{da}$  : cluster-specific productivity
- $\iota_{\omega}$  : firm-specific productivity
- $\iota_i$  : sorting from inventor-specific productivity

# IV

## Endogeneity concerns

1. Sorting from inventor unobservable shocks
  - ▶ Example: inventors select into a new cluster where less/more productive
  - ▶ Downward/upward bias
2. Sorting from cluster unobservable shocks
  - ▶ Example: growth expectations for Chemistry in Dusseldorf
  - ▶ Upward bias

# IV

- Ideal experiment: randomize inventors' location  $\Rightarrow$  regress inventor productivity vs cluster size
- The Reunification of Germany in 1990
  - ▶ Arrival of East German inventors across West German clusters  
 $\Rightarrow$  quasi-exogenous variation in cluster size



# IV

## Endogeneity concerns

1. Sorting from inventor unobservable shocks
  - ▶ Example: inventors select into a new cluster where less/more productive
  - ▶ Downward/upward bias
2. Sorting from cluster unobservable shocks
  - ▶ Example: growth expectations for Chemistry in Dusseldorf
  - ▶ Upward bias

## IV

- Ideal experiment: randomize inventors' location  $\Rightarrow$  regress inventor productivity vs cluster size
- The Reunification of Germany in 1990
  - ▶ Arrival of East German inventors across West German clusters  
 $\Rightarrow$  quasi-exogenous variation in cluster size

# IV

## Endogeneity concerns

1. Sorting from inventor unobservable shocks
  - ▶ Example: inventors select into a new cluster where less/more productive
  - ▶ Downward/upward bias
2. Sorting from cluster unobservable shocks
  - ▶ Example: growth expectations for Chemistry in Dusseldorf
  - ▶ Upward bias

# IV

- Ideal experiment: randomize inventors' location  $\Rightarrow$  regress inventor productivity vs cluster size
- The Reunification of Germany in 1990
  - ▶ Arrival of East German inventors across West German clusters  
 $\Rightarrow$  quasi-exogenous variation in cluster size

# IV

## Endogeneity concerns

1. Sorting from inventor unobservable shocks
  - ▶ Example: inventors select into a new cluster where less/more productive
  - ▶ Downward/upward bias
2. Sorting from cluster unobservable shocks
  - ▶ Example: growth expectations for Chemistry in Dusseldorf
  - ▶ Upward bias

## IV

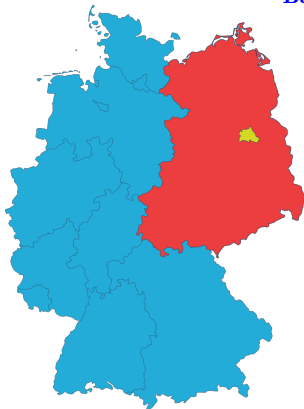
- Ideal experiment: randomize inventors' location  $\Rightarrow$  regress inventor productivity vs cluster size
- The Reunification of Germany in 1990
  - ▶ Arrival of East German inventors across West German clusters  
 $\Rightarrow$  quasi-exogenous variation in cluster size

# EMPIRICS

1. Data
2. Local Knowledge Spillovers in R&D
  - ⇒ The Reunification of Germany
  - ⇒ IV

# THE REUNIFICATION OF GERMANY

## Background



- 1961: Migration between East and West Germany ceased in 1961
  - ▶ 17 years after the German Division
- October 1990: Reunification of Germany begins
  - ▶ unexpected and permanent
  - ▶ East-West migration, including inventors (Hoisl et al., 2016)

# EMPIRICS

1. Data
2. Local Knowledge Spillovers in R&D
  - ⇒ The Reunification of Germany
  - ⇒ IV

# IV

## Model in first differences

$$\Delta \log \left( Z_{da,t}^{i\omega} \right) = \iota_{d,t} + \iota_{a,t} + \beta \Delta \log (R_{da,t}) + \epsilon_{da,t}^{i\omega}$$

## Shift-share instrument

$$IV_{da,t} = \sum_{o \in \mathcal{E}} g_{o,t} \times s_{o,da}$$

# IV

## Model in first differences

$$\Delta \log \left( Z_{da,t}^{i\omega} \right) = \iota_{d,t} + \iota_{a,t} + \beta \Delta \log (R_{da,t}) + \epsilon_{da,t}^{i\omega}$$

## Shift-share instrument

$$IV_{da,t} = \sum_{o \in \mathcal{E}} g_{o,t} \times s_{o,da}$$



# IV

## Model in first differences

$$\Delta \log \left( Z_{da,t}^{i\omega} \right) = \iota_{d,t} + \iota_{a,t} + \beta \Delta \log \left( R_{da,t} \right) + \epsilon_{da,t}^{i\omega}$$

## Shift-share instrument

$$IV_{da,t} = \sum_{o \in \mathcal{E}} g_{o,t} \times s_{o,da}$$

- $g_{o,t} \equiv \log \left( R_{o,t}^{-d,-a} \right)$ : # of inventors moved from location  $o \in \mathcal{E}$  (in the East) to all West German clusters except to the instrumented cluster  $(d, a)$
- Identification:  $\mathbb{E} \{ \overline{g\epsilon} \} = 0$  (Borusyak et al., 2022)

# IV

## Model in first differences

$$\Delta \log \left( Z_{da,t}^{i\omega} \right) = \iota_{d,t} + \iota_{a,t} + \beta \Delta \log (R_{da,t}) + \epsilon_{da,t}^{i\omega}$$

## Shift-share instrument

$$IV_{da,t} = \sum_{o \in \mathcal{E}} g_{o,t} \times s_{o,da}$$

- $s_{o,da} \equiv dist_{o,d}^{-1} \times TechComp_{o,a}$ , where

$\Rightarrow dist_{o,d}^{-1}$ : inverse distance between  $o \in \mathcal{E}$  and  $d$

$\Rightarrow TechComp_{o,a}$ : share of patents of area  $a$  in location  $o \in \mathcal{E}$

↑ CLUSTER SIZE  $\Rightarrow$  ↑ INVENTOR PRODUCTIVITY

	<i>IV</i>			<i>OLS</i>
	(1)	(2)	(3)	(4)
$\Delta \log(R_{da,t})$	0.178 (0.0431)	0.309 (0.101)	0.409 (0.152)	0.232 (0.082)
$\iota_{d,t}$		✓	✓	✓
$\iota_{a,t}$			✓	✓
<i>F stat</i>	132.1	34.14	28.23	.
<i>N</i>	50,778	50,776	50,776	53,145

# SPATIAL MODEL OF INNOVATION

1. Model
2. Taking the model to the data
3. R&D policy counterfactuals:
  - 3.1  $\Downarrow$  Inventor migration costs
  - 3.2 *2020 German R&D Tax Allowance Act* VS Optimal R&D subsidies

# SPATIAL MODEL OF INNOVATION

1. Model
2. Taking the model to the data
3. R&D policy counterfactuals:
  - 3.1  $\Downarrow$  Inventor migration costs
  - 3.2 *2020 German R&D Tax Allowance Act* VS Optimal R&D subsidies

# MODEL

## Geography

- $\mathcal{S} \equiv \{1, 2, \dots, S\}$  locations       $o, d \in \mathcal{S}$

## Technology

- Final goods
  - ▶ Non-tradable
  - ▶ CES aggregate of intermediate inputs with elast.  $\sigma$
- Intermediate inputs
  - ▶ Tradable
  - ▶ Workers produce inputs
- R&D subsidiary
  - ▶ Owned by colocated intermediate inputs firm
  - ▶ R&D output freely transmitted to intermediate inputs firm
  - ▶ Inventors produce R&D  $\Rightarrow$  input quality
    - ▶ R&D s.t. Local Knowledge Spillovers

## Agents

- Workers and inventors
- Inelastic labor supply
- Consume local final good + housing
- Location choice s.t. migration costs

# MODEL

## Geography

- $\mathcal{S} \equiv \{1, 2, \dots, S\}$  locations       $o, d \in \mathcal{S}$

## Technology

- Final goods
  - ▶ Non-tradable
  - ▶ CES aggregate of intermediate inputs with elast.  $\sigma$
- Intermediate inputs
  - ▶ Tradable
  - ▶ Workers produce inputs
- R&D subsidiary
  - ▶ Owned by colocated intermediate inputs firm
  - ▶ R&D output freely transmitted to intermediate inputs firm
  - ▶ Inventors produce R&D  $\Rightarrow$  input quality
    - ▶ R&D s.t. Local Knowledge Spillovers

## Agents

- Workers and inventors
- Inelastic labor supply
- Consume local final good + housing
- Location choice s.t. migration costs

# MODEL

## Geography

- $\mathcal{S} \equiv \{1, 2, \dots, S\}$  locations       $o, d \in \mathcal{S}$

## Technology

- Final goods
  - ▶ Non-tradable
  - ▶ CES aggregate of intermediate inputs with elast.  $\sigma$
- Intermediate inputs
  - ▶ Tradable
  - ▶ Workers produce inputs
- R&D subsidiary
  - ▶ Owned by colocated intermediate inputs firm
  - ▶ R&D output freely transmitted to intermediate inputs firm
  - ▶ Inventors produce R&D  $\Rightarrow$  input quality
    - ▶ R&D s.t. Local Knowledge Spillovers

## Agents

- Workers and inventors
- Inelastic labor supply
- Consume local final good + housing
- Location choice s.t. migration costs



## INTERMEDIATE INPUTS

$$\begin{aligned} \max_{\{P_{od}, Q_{od}, L_{od}\}} \quad & \pi_o = \sum_d \pi_{od}, \\ \text{s.t.} \quad & \\ & \pi_{od} = P_{od}Q_{od} - w_o^L L_{od}, \\ & L_{od} = \frac{\tau_{od}Q_{od}}{\mathcal{A}_o}, \\ & Q_{od} = Z_o P_{od}^{-\sigma} P_d^{\sigma-1} X_d. \end{aligned}$$

## INTERMEDIATE INPUTS

$$\begin{aligned} \max_{\{P_{od}, Q_{od}, L_{od}\}} \quad & \pi_o = \sum_d \pi_{od}, \\ \text{s.t.} \quad & \\ & \pi_{od} = P_{od} Q_{od} - w_o^L L_{od}, \\ & L_{od} = \frac{\tau_{od} Q_{od}}{\mathcal{A}_o}, \\ & Q_{od} = Z_o P_{od}^{-\sigma} P_d^{\sigma-1} X_d. \end{aligned}$$

## INTERMEDIATE INPUTS

$$\max_{\{P_{od}, Q_{od}, L_{od}\}} \pi_o = \sum_d \pi_{od},$$

*s.t.*

$$\pi_{od} = P_{od}Q_{od} - w_o^L L_{od},$$

$$L_{od} = \frac{\tau_{od} Q_{od}}{\mathcal{A}_o},$$

$$Q_{od} = Z_o P_{od}^{-\sigma} P_d^{\sigma-1} X_d.$$

# INTERMEDIATE INPUTS

$$\max_{\{P_{od}, Q_{od}, L_{od}\}} \pi_o = \sum_d \pi_{od},$$

s.t.

$$\pi_{od} = P_{od}Q_{od} - w_o^L L_{od},$$

$$L_{od} = \frac{\tau_{od}Q_{od}}{\mathcal{A}_o},$$

$$Q_{od} = Z_o P_{od}^{-\sigma} P_d^{\sigma-1} X_d.$$

» Markup pricing

» Demand for intermediates

# QUALITY OF INTERMEDIATE INPUTS

$$Z_o = \mathbb{Z}_o R_o$$

# QUALITY OF INTERMEDIATE INPUTS

$$Z_o = \mathbb{Z}_o R_o$$

- $R_o$  : # of inventors in  $o$

# QUALITY OF INTERMEDIATE INPUTS

$$Z_o = \mathbb{Z}_o R_o$$

- $\mathbb{Z}_o$  : *expected* productivity of inventors' ideas

►► Microfoundation 1: linear improvements

►► Microfoundation 2: necessary tasks

# LOCAL KNOWLEDGE SPILLOVERS IN R&D

## Productivity of inventors' ideas

►► Microfoundation

$$Z_o^i \sim \text{Frechet} \left( \alpha, \lambda_o^{\frac{1}{\alpha}} \right)$$

where

- $\lambda_o^{\frac{1}{\alpha}} = \mathcal{Z}_o R_o^{\tilde{\gamma}}$ , where  $R_o^{\tilde{\gamma}}$  and  $\tilde{\gamma} \equiv \frac{\gamma}{\alpha}$  are Local Knowledge Spillovers in R&D

## Expected productivity of inventors' ideas

$$\mathbb{Z}_o = \mathbb{E} \left\{ Z_o^i \right\} = \psi \lambda_o^{\frac{1}{\alpha}} = \psi \mathcal{Z}_o R_o^{\tilde{\gamma}}$$



# LOCAL KNOWLEDGE SPILLOVERS IN R&D

## Productivity of inventors' ideas

►► Microfoundation

$$Z_o^i \sim \text{Frechet} \left( \alpha, \lambda_o^{\frac{1}{\alpha}} \right)$$

where

- $\lambda_o^{\frac{1}{\alpha}} = \mathcal{Z}_o \mathbf{R}_o^{\tilde{\gamma}}$ , where  $\mathbf{R}_o^{\tilde{\gamma}}$  and  $\tilde{\gamma} \equiv \frac{\gamma}{\alpha}$  are Local Knowledge Spillovers in R&D

## Expected productivity of inventors' ideas

$$\mathbb{Z}_o = \mathbb{E} \left\{ Z_o^i \right\} = \psi \lambda_o^{\frac{1}{\alpha}} = \psi \mathcal{Z}_o \mathbf{R}_o^{\tilde{\gamma}}$$

# R&D

- R&D subsidiary maximizes R&D output:

$$\max_{\{R_o\}} Z_o - w_o^R R_o$$

s.t.

$$Z_o = \psi Z_o R_o^{1+\tilde{\gamma}}$$

- Demand for inventors

$$w_o^R = \psi Z_o R_o^{\tilde{\gamma}}$$

# LOCATION CHOICE

- Agent  $i$  of type  $n = \{L, R\}$  working in  $o$  moves to  $d$ :

$$U_{od}^{i,n} = \max_{d \in S} \left\{ \frac{U_d^n}{\mu_{od}^n} \times \epsilon^i \right\},$$

where

- ▶  $U_d^n = \frac{\mathcal{B}_d^n V_d^n}{P_d^\beta r_d^{1-\beta}}$  : indirect utility
- ▶  $V_d^n = \frac{(1+\pi)w_d^n}{\beta}$  : income
- ▶  $\mathcal{B}_d^n$  : type-specific location amenities
- ▶  $\epsilon^i \stackrel{iid}{\sim} G(\epsilon) = \exp(-\epsilon^{-\kappa})$
- ▶  $\mu_{od}^n$  : iceberg migration costs

- Migration shares:

$$\eta_{od}^n = \frac{\left( \frac{U_d^n}{\mu_{od}^n} \right)^\kappa}{\sum_\delta \left( \frac{U_\delta^n}{\mu_{o\delta}^n} \right)^\kappa}, \quad n = \{L, R\}$$

► Details

# EQUILIBRIUM

Given the exogenous distribution of workers and inventors across locations  $\{\bar{R}_o, \bar{L}_o\}_{\forall o \in \mathcal{S}}$ , fixed supply of housing  $\{\bar{H}_o\}_{\forall o \in \mathcal{S}}$ , location fundamentals  $\{Z_o, \mathcal{A}_o\}_{\forall o \in \mathcal{S}}$ , location amenities  $\{\mathcal{B}_o^R, \mathcal{B}_o^L\}_{\forall o \in \mathcal{S}}$ , migration costs  $\{\mu_{od}^R, \mu_{od}^L\}_{\forall o, d \in \mathcal{S}, \mathcal{S}}$ , trade costs  $\{\tau_{od}\}_{\forall o, d \in \mathcal{S}, \mathcal{S}}$ , and parameters, *an equilibrium* is a set of wages  $\{w_o^R, w_o^L\}_{\forall o \in \mathcal{S}}$ , housing rent  $\{r_o\}_{\forall o \in \mathcal{S}}$ , prices  $\{P_o\}_{\forall o \in \mathcal{S}}$ , quantities  $\{R_o, L_o, H_o, Q_o\}_{\forall o \in \mathcal{S}}$ , and quality  $\{Z_o\}_{\forall o \in \mathcal{S}}$  such that

1. *workers and inventors maximize utility*
2. *firms maximize profits*
3. *workers and inventors labor markets clear*
4. *housing market clears*
5. *trade is balanced*

► Details

► Details

► Details

► Equilibrium with RD subsidies

# SPATIAL MODEL OF INNOVATION

1. Model
2. Taking the model to the data
3. R&D policy counterfactuals:
  - 3.1  $\Downarrow$  Inventor migration costs
  - 3.2 *2020 German R&D Tax Allowance Act* VS Optimal R&D subsidies

# TAKING THE MODEL TO THE DATA

- Local Knowledge Spillovers in R&D ( $\tilde{\gamma}$ )
- Migration costs  $\{\mu_{od}^n\}^{n=\{L,R\}}$
- Trade costs  $\{\tau_{od}\}$
- Location fundamentals  $\{\mathcal{A}_o, \mathcal{Z}_o\}$
- Location amenities  $\{\mathcal{B}_o^n\}^{n=\{L,R\}}$

[» Details](#)[» Details](#)[» Details](#)[» Details](#)

# LOCAL KNOWLEDGE SPILLOVERS IN R&D ( $\tilde{\gamma}$ )

- From properties of the Frechet distribution:

$$\log \left( Z_o^i \right) = \tilde{\gamma} \log \left( R_o \right) + \epsilon_o^i$$

- Reduced-form evidence:

$$\Delta \log \left( Z_{oa,t}^{i\omega} \right) = FEs + \underbrace{\beta}_{0.409} \Delta \log \left( R_{oa,t} \right) + \Delta \epsilon_{oa,t}^{i\omega}$$

- Lanjouw and Schankerman (2004): Elasticity of patent quality to 5-year forward citations = 0.22  
 $\Rightarrow \tilde{\gamma} = (0.22) \beta \approx 0.09$  VS  $\tilde{\gamma} = 0.07$  (Moretti, 2021)

# SPATIAL MODEL OF INNOVATION

1. Model
2. Taking the model to the data
3. R&D policy counterfactuals:
  - 3.1  $\Downarrow$  Inventor migration costs
  - 3.2 *2020 German R&D Tax Allowance Act* VS Optimal R&D subsidies

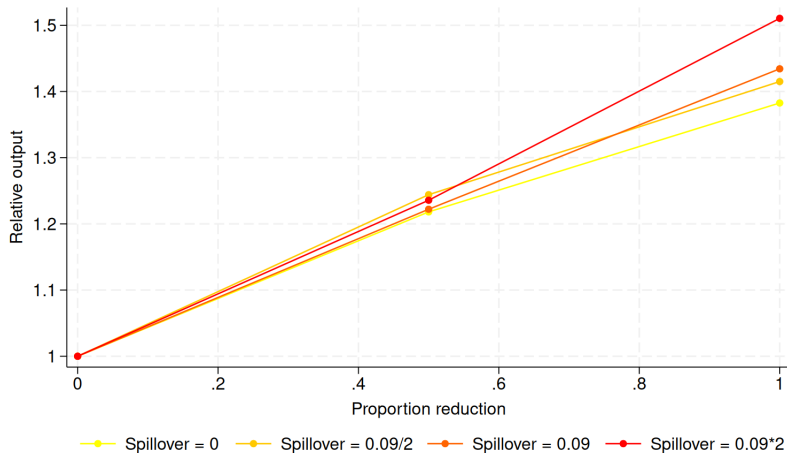


# SPATIAL MODEL OF INNOVATION

1. Model
2. Taking the model to the data
3. R&D policy counterfactuals:
  - 3.1 ↓ Inventor migration costs
  - 3.2 *2020 German R&D Tax Allowance Act* VS Optimal R&D subsidies

## ⇓ INVENTOR MIGRATION COSTS

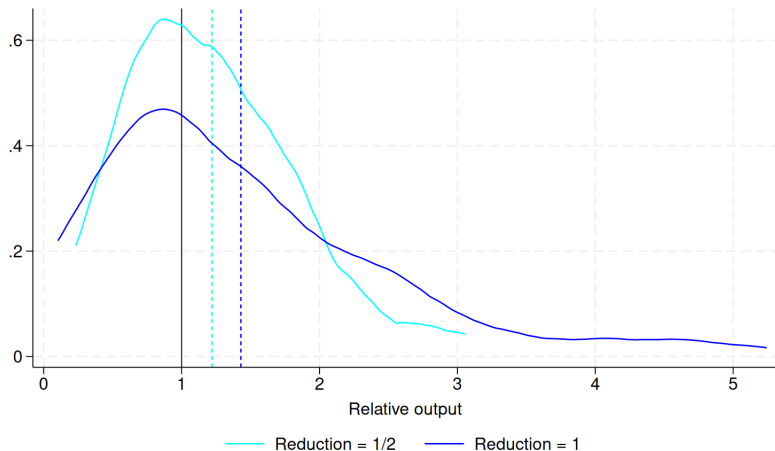
Reducing migration costs for inventors is key to promote economic activity



- X-axis:  $\widehat{\mu_{od}^R} = \mu_{od}^{R(1-\kappa)}$
- Y-axis:  $\mathbb{E} \left\{ \frac{\widehat{Q_{od}}}{Q_{od}} \right\}^{\gamma=\gamma^*}$

# ⇓ INVENTOR MIGRATION COSTS

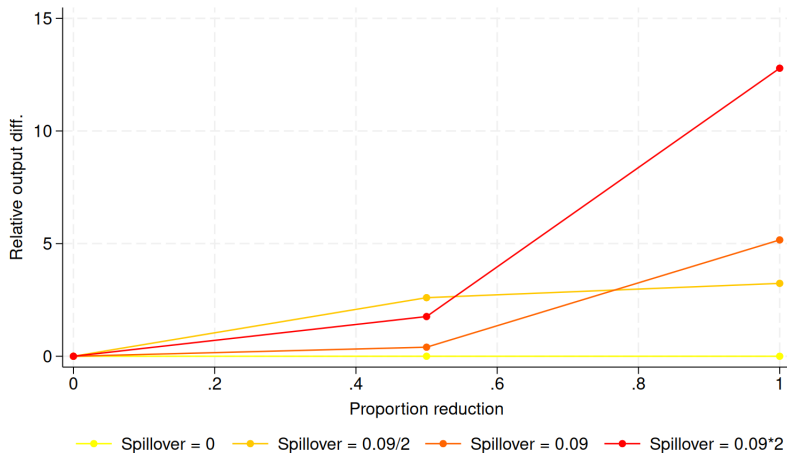
Large heterogeneous effects



- X-axis:  $\mathbb{E} \left\{ \widehat{\frac{Q_{od}}{Q_{od}}} \right\}$
- Given  $\tilde{\gamma} = 0.09$

## ↓ INVENTOR MIGRATION COSTS

## Complementarity between spillovers and reduction in inventor migration costs



- X-axis:  $\widehat{\mu_{od}^R} = \mu_{od}^{R(1-\kappa)}$
- Y-axis:  $\mathbb{E} \left\{ \frac{\widehat{Q_{od}}}{Q_{od}} \right\}^{\gamma=\gamma^*} - \mathbb{E} \left\{ \frac{\widehat{Q_{od}}}{Q_{od}} \right\}^{\gamma=0}$

# SPATIAL MODEL OF INNOVATION

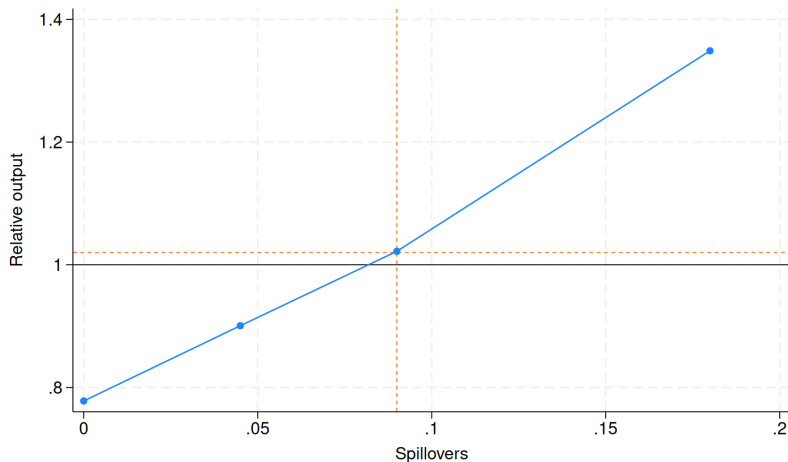
1. Model
2. Taking the model to the data
3. R&D policy counterfactuals:
  - 3.1  $\Downarrow$  Inventor migration costs
  - 3.2 *2020 German R&D Tax Allowance Act* VS Optimal R&D subsidies

# 2020 GERMAN R&D TAX ALLOWANCE ACT

- 2020 German R&D Tax Allowance Act
  - ▶ 25% subsidy to all R&D expenditures
  - ▶ blind to geography

# 2020 GERMAN R&D TAX ALLOWANCE ACT

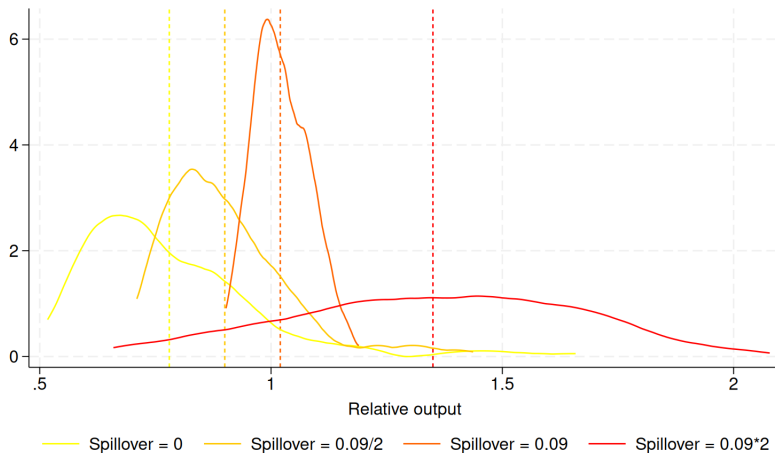
The 2020 R&D Act would increase output by 2.2% on average



- X-axis:  $\gamma$
- Y-axis:  $\mathbb{E} \left\{ \widehat{\frac{Q_{od}}{Q_{od}}} \right\}^{\gamma=\tilde{\gamma}}$

# 2020 GERMAN R&D TAX ALLOWANCE ACT

## Large heterogeneous effects



- X-axis:  $\mathbb{E} \left\{ \frac{\widehat{Q_{od}}}{Q_{od}} \right\}^{\widetilde{\gamma}}$



# OPTIMAL R&D SUBSIDIES

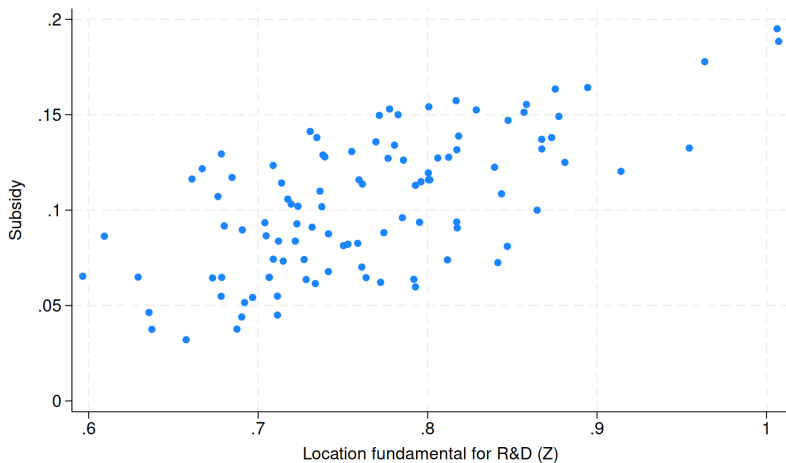
- Economy is inefficient due to spillovers  $\Rightarrow$  **Which R&D subsidies would make the economy efficient?**

1. Solve the planner problem
2. Back out set of R&D subsidies  $\{s_o^*\}$  such that Competitive Equilibrium with R&D subsidies  $\iff$  Planner Equilibrium
3. Compare  $\{s_o^*\}$  with the 2020 German R&D Tax Allowance Act

► Details

# OPTIMAL R&D SUBSIDIES

Place-based R&D policies: larger subsidies to locations with better fundamentals for R&D



- X-axis:  $Z_o$
- Y-axis:  $s_o^*$

# CONCLUSIONS

- Causal estimation of Local Knowledge Spillovers in R&D: Reunification of Germany in 1990
- Built a spatial model of innovation
  - ▶ The geography of inventors matters in the aggregate
- Implementing R&D policies in explicit geography
  - ▶ Since inventors are few, of interest to policy-makers to increase output
  - ▶ Spillovers crucial when implementing R&D policies

# BIBLIOGRAPHY I

- David S Abrams, Ufuk Akcigit, and Jillian Grennan. Patent Value and Citations: Creative Destruction or Strategic Disruption? Technical report, National Bureau of Economic Research, 2013.
- Ufuk Akcigit, Douglas Hanley, and Nicolas Serrano-Velarde. Back to Basics: Basic Research Spillovers, Innovation Policy, and Growth. *The Review of Economic Studies*, 88(1):1–43, 2021.
- Costas Arkolakis, Sun Kyoung Lee, and Michael Peters. European Immigrants and the United States’ Rise to the Technological Frontier. Technical report, mimeo, 2020.
- A. Arundel, G. van de Paal, and L. Soete. Innovation Strategies of Europe’s Largest Industrial Firms. Results of the PACE Survey for Information Sources, Public Research, Protection of Innovations and Government Programme. 1995.
- Andrew Atkeson and Ariel Tomas Burstein. Innovation, Firm Dynamics, and International Trade. *Journal of Political Economy*, 118(3):433–484, 2010.
- David B Audretsch and Maryann P Feldman. R&D Spillovers and the Geography of Innovation and Production. *The American Economic Review*, 86(3):630–640, 1996.
- Dany Bahar, Prithwiraj Choudhury, and Hillel Rapoport. Migrant Inventors and the Technological Advantage of Nations. *Research Policy*, 49(9):103947, 2020.

## BIBLIOGRAPHY II

- Shai Bernstein, Rebecca Diamond, Abhisit Jiranaphawiboon, Timothy McQuade, and Beatriz Pousada. The contribution of high-skilled immigrants to innovation in the united states. Technical report, National Bureau of Economic Research, 2022.
- Duncan Black and Vernon Henderson. A Theory of Urban Growth. *Journal of Political Economy*, 107(2):252–284, 1999.
- Knut Blind, Jakob Edler, Rainer Frietsch, and Ulrich Schmoch. Motives to Patent: Empirical Evidence from Germany. *Research policy*, 35(5):655–672, 2006.
- Nicholas Bloom, Mark Schankerman, and John Van Reenen. Identifying Technology Spillovers and Product Market Rivalry. *Econometrica*, 81(4):1347–1393, 2013.
- George J Borjas and Kirk B Doran. The Collapse of the Soviet Union and the Productivity of American Mathematicians. *The Quarterly Journal of Economics*, 127(3):1143–1203, 2012.
- Kirill Borusyak, Peter Hull, and Xavier Jaravel. Quasi-Experimental Shift-share Research Designs. *The Review of Economic Studies*, 89(1):181–213, 2022.
- Valentina Bosetti, Cristina Cattaneo, and Elena Verdolini. Migration of Skilled Workers and Innovation: A European Perspective. *Journal of International Economics*, 96(2):311–322, 2015.

## BIBLIOGRAPHY III

- Christian Broda and David E Weinstein. Globalization and the Gains from Variety. *The Quarterly Journal of Economics*, 121(2):541–585, 2006.
- Gharad Bryan and Melanie Morten. The Aggregate Productivity Effects of Internal Migration: Evidence from Indonesia. *Journal of Political Economy*, 127(5):2229–2268, 2019.
- Konrad B Burchardi and Tarek A Hassan. The Economic Impact of Social Ties: Evidence from German Reunification. *The Quarterly Journal of Economics*, 128(3):1219–1271, 2013.
- Konrad B Burchardi, Thomas Chaney, Tarek Alexander Hassan, Lisa Tarquinio, and Stephen J Terry. Immigration, Innovation, and Growth. Technical report, National Bureau of Economic Research, 2020.
- Gerald A Carlino, Satyajit Chatterjee, and Robert M Hunt. Urban Density and the Rate of Invention. *Journal of Urban Economics*, 61(3):389–419, 2007.
- Brad Chattergoon and William R Kerr. Winner takes all? tech clusters, population centers, and the spatial transformation of us invention. *Research Policy*, 51(2):104418, 2022.

# BIBLIOGRAPHY IV

- Wesley M Cohen, Akira Goto, Akiya Nagata, Richard R Nelson, and John P Walsh. R&D Spillovers, Patents and the Incentives to Innovate in Japan and the United States. *Research policy*, 31(8-9):1349–1367, 2002.
- Pierre-Philippe Combes, Gilles Duranton, Laurent Gobillon, and Sébastien Roux. Estimating Agglomeration Economies with History, Geology, and Worker Effects. In *Agglomeration Economics*, pages 15–66. University of Chicago Press, 2010.
- Katrin Cremers, Max Ernicke, Fabian Gaessler, Dietmar Harhoff, Christian Helmers, Luke McDonagh, Paula Schliessler, and Nicolas Van Zeebroeck. Patent litigation in Europe. *European Journal of Law and Economics*, 44(1):1–44, 2017.
- Donald R Davis and Jonathan I Dingel. A Spatial Knowledge Economy. *American Economic Review*, 109(1):153–70, 2019.
- Klaus Desmet and Esteban Rossi-Hansberg. Spatial Development. *American Economic Review*, 104(4):1211–43, 2014.
- Klaus Desmet, Dávid Krisztián Nagy, and Esteban Rossi-Hansberg. The Geography of Development. *Journal of Political Economy*, 126(3):903–983, 2018.
- Emmanuel Duguet and Isabelle Kabla. Appropriation Strategy and the Motivations to Use the Patent System: an Econometric Analysis at the Firm Level in French Manufacturing. In *The Economics and Econometrics of Innovation*, pages 267–305. Springer, 2000.

# BIBLIOGRAPHY V

- Gilles Duranton. Urban Evolutions: The Fast, the Slow, and the Still. *American Economic Review*, 97(1):197–221, 2007.
- Gilles Duranton and Diego Puga. Nursery Cities: Urban Diversity, Process Innovation, and the Life Cycle of Products. *American Economic Review*, 91(5): 1454–1477, 2001.
- Gilles Duranton and Diego Puga. Urban Growth and its Aggregate Implications. Technical report, National Bureau of Economic Research, 2019.
- Jonathan Eaton and Zvi Eckstein. Cities and Growth: Theory and Evidence from France and Japan. *Regional Science and Urban Economics*, 27(4-5):443–474, 1997.
- Jonathan Eaton and Samuel Kortum. Technology, Geography, and Trade. *Econometrica*, 70(5):1741–1779, 2002.
- Edward L Glaeser. Learning in Cities. *Journal of Urban Economics*, 46(2):254–277, 1999.
- Michael Greenstone, Richard Hornbeck, and Enrico Moretti. Identifying Agglomeration Spillovers: Evidence from Winners and Losers of Large Plant Openings. *Journal of Political Economy*, 118(3):536–598, 2010.
- Zvi Griliches. The Search for R&D spillovers. *National Bureau of Economic Research Working Paper Series*, (w3768), 1991.



# BIBLIOGRAPHY VI

- Jonathan Gruber, Simon Johnson, and Enrico Moretti. Place-Based Productivity and Costs in Science. Technical report, National Bureau of Economic Research, 2022.
- Bronwyn H Hall, Adam B Jaffe, and Manuel Trajtenberg. The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools, 2001.
- Juan Carlos Hallak and Jagadeesh Sivadasan. Product and Process Productivity: Implications for Quality Choice and Conditional Exporter Premia. *Journal of International Economics*, 91(1):53–67, 2013.
- Dietmar Harhoff, Francis Narin, Frederic M Scherer, and Katrin Vopel. Citation Frequency and the Value of Patented Inventions. *Review of Economics and Statistics*, 81(3):511–515, 1999.
- Karin Hoisl, Dietmar Harhoff, Matthias Dorner, Tina Hinz, and Stefan Bender. Social Ties or Patent Quality Signals-Evidence from East German Inventor Migration. In *Academy of Management Proceedings*, volume 2016, page 13594. Academy of Management Briarcliff Manor, NY 10510, 2016.
- Adam B Jaffe, Manuel Trajtenberg, and Rebecca Henderson. Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. *the Quarterly Journal of Economics*, 108(3):577–598, 1993.

## BIBLIOGRAPHY VII

- Adam B Jaffe, Manuel Trajtenberg, and Michael S Fogarty. Knowledge Spillovers and Patent Citations: Evidence from a Survey of Inventors. *American Economic Review*, 90(2):215–218, 2000.
- Shawn Kantor and Alexander Whalley. Research Proximity and Productivity: Long-term Evidence from Agriculture. *Journal of Political Economy*, 127(2): 819–854, 2019.
- Morgan Kelly and Anya Hageman. Marshallian Externalities in Innovation. *Journal of Economic Growth*, 4(1):39–54, 1999.
- Sari Pekkala Kerr, William Kerr, Çağlar Özden, and Christopher Parsons. High-skilled migration and agglomeration. *Annual Review of Economics*, 9: 201–234, 2017.
- William R Kerr. Breakthrough inventions and migrating clusters of innovation. *Journal of urban Economics*, 67(1):46–60, 2010.
- William R Kerr and Scott Duke Kominers. Agglomerative Forces and Cluster Shapes. *Review of Economics and Statistics*, 97(4):877–899, 2015.
- Leonid Kogan, Dimitris Papanikolaou, Amit Seru, and Noah Stoffman. Technological Innovation, Resource Allocation, and Growth. *The Quarterly Journal of Economics*, 132(2):665–712, 2017.

## BIBLIOGRAPHY VIII

- Samuel S Kortum. Research, patenting, and technological change. *Econometrica: Journal of the Econometric Society*, pages 1389–1419, 1997.
- Oliver Krebs and Michael Pflüger. On the road (again): Commuting and local employment elasticities in germany. 2021.
- Paul Krugman. Scale Economies, Product Differentiation, and the Pattern of Trade. *The American Economic Review*, 70(5):950–959, 1980.
- Jean O Lanjouw and Mark Schankerman. Patent quality and research productivity: Measuring innovation with multiple indicators. *The economic journal*, 114(495): 441–465, 2004.
- Marc J Melitz. The Impact of Trade on Intra-industry Reallocations and Aggregate Industry Productivity. *Econometrica*, 71(6):1695–1725, 2003.
- Martí Mestieri, Enrico Berkes, and Ruben Gaetani. Cities and Technological Waves. 2021.
- Joan Monras. Economic Shocks and Internal Migration. 2018.
- Enrico Moretti. The Effect of High-tech Clusters on the Productivity of Top Inventors. *American Economic Review*, 111(10):3328–75, 2021.
- Petra Moser, Alessandra Voena, and Fabian Waldinger. German Jewish émigrés and US invention. *American Economic Review*, 104(10):3222–55, 2014.

# BIBLIOGRAPHY IX

- Dávid Krisztián Nagy et al. City Location and Economic Development. *Princeton University, mimeograph*, 2016.
- Nikolaos Papageorgiadis and Wolfgang Sofka. Patent enforcement across 51 countries—Patent enforcement index 1998–2017. *Journal of World Business*, 55(4): 101092, 2020.
- Heitor S Pellegrina and Sebastian Sotelo. Migration, Specialization, and Trade: Evidence from Brazil’s March to the West. Technical report, National Bureau of Economic Research, 2021.
- Giovanni Peri, Kevin Shih, and Chad Sparber. STEM workers, H-1B visas, and productivity in US cities. *Journal of Labor Economics*, 33(S1):S225–S255, 2015.
- Michael Peters. Market Size and Spatial Growth: Evidence from Germany’s Post-war Population Expulsions. *Unpublished manuscript*, 2019.
- Michael Peters. Market Size and Spatial Growth: Evidence from Germany’s Post-war Population Expulsions. *Econometrica*, 90(5):2357–2396, 2022.
- Robert H Pitkethly. Intellectual Property Strategy in Japanese and UK Companies: Patent Licensing Decisions and Learning Opportunities. *Research Policy*, 30(3): 425–442, 2001.

# BIBLIOGRAPHY X

- Marta Prato. The Global Race for Talent: Brain Drain, Knowledge Transfer and Growth. *mimeo*, 2021.
- Natalia Ramondo, Andrés Rodríguez-Clare, and Milagro Saborío-Rodríguez. Trade, Domestic Frictions, and Scale Effects. *American Economic Review*, 106(10): 3159–84, 2016.
- Jorge De La Roca and Diego Puga. Learning by Working in Big Cities. *The Review of Economic Studies*, 84(1):106–142, 2017.
- H.J. Schalk, U.C. Tager, and S Brander. Wissensverbreitung und Diffusionsdynamik im Spannungsfeld zwischen innovierenden und imitierenden Unternehmen. *Ifo-Institut für Wirtschaftsforschung, München*, 1999.
- Peter Thompson. Patent Citations and the Geography of Knowledge Spillovers: Evidence from Inventor- and Examiner-added Citations. *The Review of Economics and Statistics*, 88(2):383–388, 2006.
- Manuel Trajtenberg. A Penny for your Quotes: Patent Citations and the Value of Innovations. *The RAND Journal of Economics*, pages 172–187, 1990.

# DISTRIBUTION OF INVENTORS, BY OCCUPATION

Occupation	Share
Technical research and development, construction, and production planning and scheduling	19.23%
Machine-building and automotive industry	19.10%
Mechatronics, energy electronics and electrical engineering	15.77%
Mathematics, biology, chemistry and physics	15.74%
Business management and organization	10.36%
Others	19.8%

» Back to data

# DISTRIBUTION OF ESTABLISHMENTS, BY INDUSTRY

Industry	Share
Manufacturing, mining and quarrying and other industry	38.59%
Wholesale and retail trade, transportation and storage, accommodation and food service activities	18.76%
Real estate activities	12.90%
Professional, scientific, technical, administration and support service activities	7.87%
Financial and insurance activities	5.56%
Construction	5.31%
Agriculture, forestry and fishing	4.84%
Information and communication	3.15%
Public administration, defence, education, human health and social work activities	2.29%
Other services	0.68%

# DISTRUTION OF PATENTS, BY TECHNOLOGICAL CLASS

Technological area	Share
Mechanical engineering	38.39%
Chemistry	25%
Electrical engineering	18.09%
Instruments	12.64%
Other fields	5.85%

» Back to data



## TOP 10 CITIES: ELECTRICAL ENGINEERING

<i>Code</i>	<i>City</i>	<i>Share</i>
59	Stuttgart	15.0968
80	Munchen	13.7764
90	Regensburg	5.9419
97	Nurnberg	4.5334
96	Erlangen	4.0492
65	Karlsruhe	4.0052
60	Boblingen	2.7728
74	Reutlingen	2.7288
41	Soest	2.5528
43	Frankfurt am Main	2.2007

## TOP 10 CITIES: INSTRUMENTS

<i>Code</i>	<i>City</i>	<i>Share</i>
59	Stuttgart	13.5844
80	Munchen	8.7328
64	Heidenheim	6.5068
96	Erlangen	5.7648
60	Boblingen	4.9657
43	Frankfurt am Main	4.1095
70	Rottweil	4.0525
68	Freiburg	3.4246
90	Regensburg	2.9680
65	Karlsruhe	2.8538

» Back to data

## TOP 10 CITIES: CHEMISTRY

<i>Code</i>	<i>City</i>	<i>Share</i>
24	Dusseldorf	11.0110
59	Stuttgart	10.7340
5	Hamburg	7.2022
80	Munchen	6.3019
43	Frankfurt am Main	5.6094
81	Altotting	2.9085
25	Essen	2.7008
29	Koln	2.4238
74	Reutlingen	2.4238
96	Erlangen	2.2853

» Back to data

## TOP 10 CITIES: MECHANICAL ENGINEERING

<i>Code</i>	<i>City</i>	<i>Share</i>
59	Stuttgart	15.8658
80	Munchen	8.1403
60	Boblingen	5.8589
43	Frankfurt am Main	3.5776
77	Ravensburg	3.3183
96	Erlangen	3.1973
65	Karlsruhe	3.0936
7	Wolfsburg	2.5924
24	Dusseldorf	2.5406
62	Heilbronn	2.4714

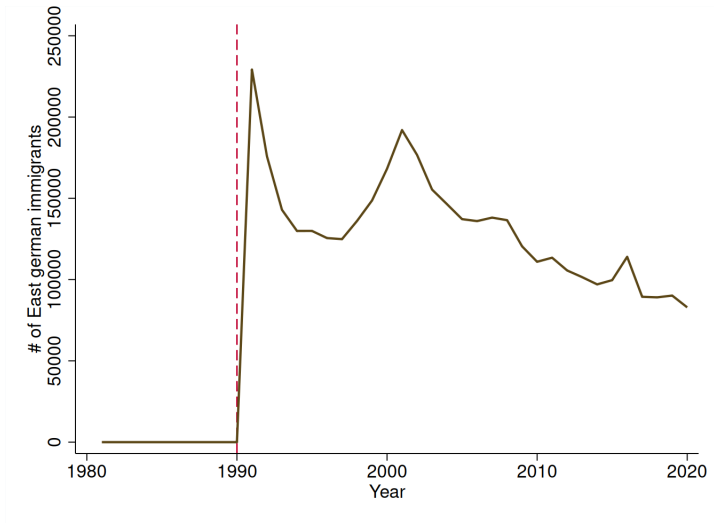
» Back to data

# GERMAN PATENT SYSTEM

- Patent systems in Germany:
  - ▶ West Germany: German Patent Office (DPA)
  - ▶ East Germany: Office of Inventions and Patents (AfEP)
- Legal frameworks almost identical before reunification
- Merged after reunification
  - ▶ Integration of 13.5 million patent documents

» Back to the Reunification

# THE EXODUS TO THE WEST



# OLS MODELS, BASELINE SPECIFICATION

	(1)	(2)	(3)	(4)	(5)	(6)
$\log(R_{da,t})$	0.0705 (0.0256)	0.111 (0.0170)	0.0985 (0.0166)	0.109 (0.0385)	0.0896 (0.0358)	0.175 (0.0660)
$l_{d,t}$		✓	✓	✓	✓	✓
$l_{a,t}$			✓	✓	✓	✓
$l_{da}$				✓	✓	✓
$l_{\omega}$					✓	✓
$l_i$						✓
$N$	177,301	177,300	177,300	177,294	162,803	84,639
$R^2$	0.008	0.053	0.064	0.079	0.246	0.700

# OLS MODELS, ROBUSTNESS

<i>Panel A: <math>\log(1 + Z)</math></i>						
	(1)	(2)	(3)	(4)	(5)	(6)
EPO	0.117 (0.0186)	0.143 (0.0173)	0.224 (0.0135)	0.184 (0.0319)	0.0859 (0.0349)	0.173 (0.0679)
EU	0.142 (0.0208)	0.193 (0.0162)	0.255 (0.0178)	0.203 (0.0461)	0.103 (0.0463)	0.245 (0.0864)
$l_{d,t}$		✓	✓	✓	✓	✓
$l_{a,t}$			✓	✓	✓	✓
$l_{da}$				✓	✓	✓
$l_{\omega}$					✓	✓
$l_i$						✓
$N$	177,301	177,300	177,300	177,294	162,803	84,639



# OLS MODELS, ROBUSTNESS

<i>Panel B: IHS (Z)</i>						
	(1)	(2)	(3)	(4)	(5)	(6)
DPMA	0.0847 (0.0326)	0.135 (0.0209)	0.118 (0.0205)	0.130 (0.0475)	0.108 (0.0440)	0.217 (0.0798)
EPO	0.140 (0.0219)	0.171 (0.0204)	0.266 (0.0160)	0.223 (0.0389)	0.102 (0.0431)	0.214 (0.0810)
EU	0.142 (0.0208)	0.193 (0.0162)	0.255 (0.0178)	0.203 (0.0461)	0.103 (0.0463)	0.245 (0.0864)
$l_{d,t}$		✓	✓	✓	✓	✓
$l_{a,t}$			✓	✓	✓	✓
$l_{da}$				✓	✓	✓
$l_{\omega}$					✓	✓
$l_i$						✓
$N$	177, 301	177, 300	177, 300	177, 294	162, 803	84, 639

# OLS MODELS, 5-YEAR PERIODS

	(1)	(2)	(3)	(4)	(5)	(6)
$\log(1 + Z)$	0.0291 (0.0096)	0.0472 (0.007)	0.0449 (0.0073)	0.0707 (0.0146)	0.0664 (0.0135)	0.0907 (0.0215)
$IHS(Z)$	0.0368 (0.0124)	0.060 (0.0089)	0.0568 (0.0094)	0.0902 (0.0187)	0.0850 (0.0171)	0.116 (0.0273)
$\iota_{d,t}$		✓	✓	✓	✓	✓
$\iota_{a,t}$			✓	✓	✓	✓
$\iota_{da}$				✓	✓	✓
$\iota_{\omega}$					✓	✓
$\iota_i$						✓
$N$	177,301	177,300	177,300	177,294	162,803	84,639

## IV MODELS, ROBUSTNESS

	<i>Panel A: <math>\Delta \log(1 + Z)</math></i>		
	(1)	(2)	(3)
EPO	0.164 (0.0422)	0.139 (0.0723)	0.209 (0.117)
EU	0.210 (0.0436)	0.270 (0.0907)	0.343 (0.143)
$\iota_{d,t}$		✓	✓
$\iota_{a,t}$			✓
$KP - F$	132.1	34.14	28.23
$N$	50,778	50,776	50,776

# IV MODELS, ROBUSTNESS

<i>Panel B: <math>\Delta IHS(Z)</math></i>			
	(1)	(2)	(3)
DPMA	0.215 (0.0514)	0.380 (0.122)	0.498 (0.184)
EPO	0.182 (0.0494)	0.144 (0.0849)	0.237 (0.140)
EU	0.235 (0.0588)	0.304 (0.104)	0.393 (0.168)
$\iota_{d,t}$		✓	✓
$\iota_{a,t}$			✓
$KP - F$	132.1	34.14	28.23
$N$	50,778	50,776	50,776

## IV MODELS, 5-YEAR PERIODS

	(1)	(2)	(3)
$\Delta \log (1+Z)$	0.0367 (0.0232)	0.0865 (0.0331)	0.0849 (0.0428)
$\Delta IHS(Z)$	0.0464 (0.0295)	0.109 (0.0420)	0.104 (0.0543)
$l_{d,t}$		✓	✓
$l_{a,t}$			✓
$KP - F$	85.96	26.64	38.15
$N$	100,234	100,228	100,228

# DISCUSSIONS

1. Do citations measure productivity?
2. Exposure instead of knowledge spillovers?
3. Comparison to previous estimates

# DO CITATIONS MEASURE PRODUCTIVITY?

- Positive relationship between number of citations and proxies for productivity, such as patent value (Kogan et al., 2017; Hall et al., 2001; Harhoff et al., 1999; Trajtenberg, 1990)
- More recently, preliminary evidence of a inverse U-shaped relationship between number of citations and patent value in the data Abrams et al. (2013)
  - ▶ Productive vs strategic patents
  - ▶ Are German patents mostly productive or strategic?
- Literature on firm surveys about their incentives to patent (Blind et al., 2006; Cohen et al., 2002; Pitkethly, 2001; Duguet and Kabla, 2000; Schalk et al., 1999; Arundel et al., 1995)
  - ▶ Main motive of German firms to file patents: protection of ideas  $\Rightarrow$  productive  $\Rightarrow$  positive relationship

# EXPOSURE INSTEAD OF KNOWLEDGE SPILLOVERS?

- Identification threat: # citations reflect higher exposure of an inventor's ideas
  - ▶ upward bias
- 2 arguments against this concern:
  1. Germany reports one of the largest number of patent litigation cases (Cremers et al., 2017), and exhibits one of the highest cross-country levels of patent enforcement (Papageorgiadis and Sofka, 2020).
  2. Estimations based on EPO citations



# COMPARISON TO PREVIOUS ESTIMATES

- Carlino et al. (2007):  $\uparrow 10\%$  population  $\Rightarrow \uparrow 1.95\%$  rate of patenting per-capita across US MAs
  1. Inventor productivity VS US MAs patenting rates
  2. Knowledge spillovers in R&D VS Overall knowledge spillovers
  3. Identification from natural experiment VS Controls
- Moretti (2021):  $\uparrow 10\%$  cluster size  $\Rightarrow \uparrow 0.5\%$  inventor productivity
  1. Long-run vs short-run elasticities
  2. Germany vs US

# MICROFOUNDATION: GENERATION OF IDEAS

- Innovation *a la* Kortum (1997)
- Consider inventor  $i$  living in  $o$
- Steps:
  1. Inventor  $i$  draws idea  $j \in [1, T_o]$  with productivity  $Z^{ij}$
  2. Selects the best idea, so  $Z_o^i = \max_{j=1, \dots, T_o} Z^{ij}$
  3. If  $T_o \sim \text{Poisson}(\lambda_o)$  and  $Z^{ij} \sim \text{Pareto}(\alpha)$   
 $\Rightarrow Z_o^i \sim \text{Frechet}\left(\alpha, \lambda_o^{\frac{1}{\alpha}}\right)$ ,  
where  $\lambda_o$  is the *spillover function*

# MICROFOUNDATION I: LINEAR IMPROVEMENT

- Steps:
  1. Inventors  $R_o$  show up to work and line up
  2. first in line receives blueprint, improves it, passes it over
- Endogenous quality:

$$Z_o = \mathbb{Z}_o R_o,$$

where  $\mathbb{Z}_o^\omega \equiv \mathbb{E} \{ Z_o^{i\omega} \} = \Gamma \left( 1 - \frac{1}{\alpha} \right) \lambda_o^{\frac{1}{\alpha}}$ , where  $\Gamma(\cdot)$  is the Gamma function

# MICROFOUNDATION II: NECESSARY TASKS

- Steps:

1. A blueprint is continuum of *necessary* tasks  $\mathcal{T} \equiv [0, 1]$
2. Aggregate quality improvements

$$Z_o = \exp \left( \int_{\mathcal{T}} \log (Z_o(t)) dt \right)$$

3. Quality of task  $t \in \mathcal{T}$

$$Z_o(t) = Z(t) R_o,$$

where  $Z(t)$  is drawn from  $Z_o^i$

4. Rewrite quality as

$$Z_o = \exp \left( \frac{\bar{\gamma}}{\alpha} \right) \lambda_o^{\frac{1}{\alpha}} R_o,$$

where  $\bar{\gamma}$  is Euler's constant

# DEMAND OF INTERMEDIATES

- Final good: CES aggregator of intermediates

$$Q_d = \left( \sum_o Z_o^{\frac{1}{\sigma}} Q_{od}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

- Demand for intermediates:

$$Q_{od} = Z_o P_{od}^{-\sigma} P_d^{\sigma-1} X_d,$$

where  $X_d \equiv P_d Q_d$ , and  $P_d^{1-\sigma} = \sum_o Z_o P_{od}^{1-\sigma}$ .

# FIRM OPTIMIZATION

- Firms maximize profits:

$$\max_{\{P_{od}, Q_{od}, L_{od}\}} \pi_o = \sum_d \pi_{od},$$

s.t.

$$\pi_{od} = P_{od} Q_{od} - w_o^L L_{od},$$

$$L_{od} = \frac{\tau_{od} Q_{od}}{\mathcal{A}_o},$$

$$Q_{od} = Z_o P_{od}^{-\sigma} P_d^{\sigma-1} X_d.$$

- FOCs wrt  $\{P_{od}, Q_{od}, L_{od}\}$  yields markup pricing:

$$P_{od} = \bar{m} \frac{\tau_{od} w_o^L}{\mathcal{A}_o}$$

# DEMAND OF FINAL GOODS

- Preferences of agents of workers ( $n = L$ ) and inventors ( $n = R$ )
- Preferences local final good ( $q_d^n$ ) + housing ( $h_d^n$ ) + location amenities ( $\mathcal{B}_d^n$ ):

$$\begin{aligned} \max_{\{q_d^n, h_d^n\}} U_d &= \mathcal{B}_d^n \left( \frac{q_d^n}{\beta} \right)^\beta \left( \frac{h_d^n}{1-\beta} \right)^{1-\beta} \\ \text{s.t. } P_d q_d^n + r_d h_d^n &= V_d^n, \end{aligned}$$

where  $V_d^n$  is the agent's income, and  $\beta$  is the expenditure share on local final goods.

- Indirect utility:

$$U_d^n = \frac{\mathcal{B}_d^n V_d^n}{P_d^\beta r_d^{1-\beta}}$$

- Income:

$$\begin{aligned} V_d^n &= (1 + \bar{\pi}) w_d^n + (1 - \beta) V_d^n, \\ V_d^n &= \frac{(1 + \bar{\pi}) w_d^n}{\beta}. \end{aligned}$$

# MARKET CLEARING: LABOR

## Inventors

- Supply:

$$R_d = \sum_o \eta_{od}^R \bar{R}_o$$

- Demand:

## Workers

- Supply:

$$L_d = \sum_o \eta_{od}^L \bar{L}_o$$

- Demand: not necessary due to Walras's Law



# TRADE BALANCE

- Income:

$$Y_o = \frac{(1 + \bar{\pi}) (w_o^L L_o + w_o^R R_o)}{\beta}$$

- Expenditure:

$$X_o = \sum_d \chi_{od} X_d$$

- Trade balance:

$$Y_o = X_o$$

# MARKET CLEARING: HOUSING

- Supply:

$$H_o = \overline{H}_o$$

- Demand:

$$r_o = \frac{(1 - \beta) Y_o}{H_o}$$

# EQUILIBRIUM WITH R&D SUBSIDIES

Given the exogenous distribution of workers and inventors across locations  $\{\bar{R}_o, \bar{L}_o\}_{\forall o \in \mathcal{S}}$ , fixed supply of housing  $\{\bar{H}_o\}_{\forall o \in \mathcal{S}}$ , location fundamentals  $\{\mathcal{Z}_o, \mathcal{A}_o\}_{\forall o \in \mathcal{S}}$ , location amenities  $\{\mathcal{B}_o^R, \mathcal{B}_o^L\}_{\forall o \in \mathcal{S}}$ , migration costs  $\{\mu_{od}^R, \mu_{od}^L\}_{\forall o, d \in \mathcal{S}, \mathcal{S}}$ , trade costs  $\{\tau_{od}\}_{\forall o, d \in \mathcal{S}, \mathcal{S}}$ , R&D subsidies  $\{s_o\}_{\forall o \in \mathcal{S}}$ , and parameters, *an equilibrium with R&D subsidies is a set of wages  $\{w_o^R, w_o^L\}_{\forall o \in \mathcal{S}}$ , housing rent  $\{r_o\}_{\forall o \in \mathcal{S}}$ , prices  $\{P_o\}_{\forall o \in \mathcal{S}}$ , quantities  $\{L_o, R_o, H_o, Q_o\}_{\forall o \in \mathcal{S}}$ , and quality  $\{Z_o\}_{\forall o \in \mathcal{S}}$  such that*

1. *workers and inventors maximize utility*
2. *firms maximize profits*
3. *workers and inventors labor markets clear*
4. *housing market clears*
5. *government's budget is balanced*
6. *trade is balanced*

# MIGRATION COSTS: $\{\mu_{od}^R, \mu_{od}^L\}$

- Iceberg migration costs:

$$\mu_{od}^n = \rho_0^n \text{dist}_{od}^{\rho_1^n} \exp\left(-\frac{\epsilon_{od}^n}{\kappa}\right)$$

- $\{\rho_0^n\}$  :
  - ▶ Targets: 10-year average migration rates
  - ▶  $\{\widehat{\rho}_0^L, \widehat{\rho}_0^R\} = \{25\%, 26.4\%\}$
- $\{\rho_1^n\}$  : Elasticities of migration costs to distance
  - ▶ Migration gravity equations:

▶▶ Results

$$\log(\eta_{od,t}^n) = \iota + \iota_{o,t} + \iota_{d,t} - \rho_n \kappa \log(\text{dist}_{od}) + \epsilon_{od,t}^n, \quad n = \{R, L\}$$

- ▶ Given  $\kappa = 2.12$  (Peters, 2022), PPML:

$$\left\{\rho_1^R, \rho_1^L\right\} = \left\{\frac{1.254}{2.12}, \frac{1.277}{2.12}\right\}$$

▶▶ Back

## TRADE COSTS: $\tau_{od}$

- Iceberg trade costs:

$$\tau_{od} = \xi_0 dist_{od}^{\xi_1}$$

- $\xi_0$  :
  - ▶ Target: 50% share of total intra-regional trade (Ramondo et al., 2016)
- $\xi_1$  : Elasticity of trade costs to distance
  - ▶ No data on internal data
  - ▶ Given  $\sigma = 2.5$  (Broda and Weinstein, 2006), follow Krebs and Pflüger (2021):  $\xi_1 = \frac{1.56}{\sigma-1}$

## LOCATION FUNDAMENTALS $\{\mathcal{A}_o, \mathcal{Z}_o\}$

Given parameter values  $\{\psi, \tilde{\gamma}\}$ , and data on wages and population  $\{w_o^R, R_o\}$ , there is a unique set of values for location fundamentals for R&D  $\{\mathcal{Z}_o\}$  that is consistent with the aggregate demand for inventors. Then, given trade costs  $\{\tau_{od}\}$ , parameter values  $\{\psi, \sigma, \tilde{\gamma}\}$ , and data on wages and population  $\{w_o^R, w_o^L, R_o, L_o\}$ , there is a unique set of values for location fundamental for production  $\{\mathcal{A}_o\}$  that is consistent with the data.

## LOCATION AMENITIES $\{\mathcal{B}_o^R, \mathcal{B}_o^L\}$

Given the exogenous distribution of workers and inventors across locations  $\{\bar{R}_o, \bar{L}_o\}_{\forall o \in \mathcal{S}}$ , fixed supply of housing  $\{\bar{H}_o\}_{\forall o \in \mathcal{S}}$ , trade costs  $\{\tau_{od}\}$ , migration costs  $\{\mu_{od}^R, \mu_{od}^L\}$ , fundamental location productivities  $\{\mathcal{Z}_o, \mathcal{A}_o\}$ , parameter values  $\{\alpha, \psi, \kappa, \sigma, \beta\}$ , and data on wages and population  $\{w_o^R, w_o^L, R_o, L_o\}$ , there is a unique set of values for fundamental location amenities  $\{\mathcal{B}_o^R, \mathcal{B}_o^L\}$  that is consistent with the data.

## PLANNER PROBLEM

$$\max \left( \frac{\bar{L}}{\bar{L} + \bar{R}} \right) \sum_o \bar{U}_o^L + \left( \frac{\bar{R}}{\bar{L} + \bar{R}} \right) \sum_o \bar{U}_o^R,$$

where

$$\bar{U}_o^L = \Gamma \left( \frac{\kappa - 1}{\kappa} \right) \left( \sum_d \left( \frac{U_d^L}{\mu_{od}^L} \right)^\kappa \right)^{\frac{1}{\kappa}},$$

$$\bar{U}_o^R = \Gamma \left( \frac{\kappa - 1}{\kappa} \right) \left( \sum_d \left( \frac{U_d^R}{\mu_{od}^R} \right)^\kappa \right)^{\frac{1}{\kappa}},$$

and

- Labor market clears
- Inventor market clears
- Housing market clears
- Final good market clears
- Intermediate input market clears