Inventor Mobility, Knowledge Diffusion, and Growth

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Innovation, Knowledge Diffusion, and Inventors

- Innovation and knowledge diffusion determine firm and aggregate productivity growth
- Inventors play two important roles:
  - Inventors as factor of innovation
  - Inventor mobility as intermediary for knowledge diffusion
- How do inventors' labor market frictions and policies affect firm and aggregate productivity growth?

New Theory and Data of Inventors

- Endogenous growth model with frictional labor market for inventors
  - Inventors engage in in-house R&D
  - Poaching firms learn from poached firms
- Administrative panel dataset on German inventors
  - Patent information
  - Labor market careers and wages
  - Establishments' characteristics

Findings

Empirical Analysis

- Patent productivity grows faster when a larger proportion of inventor inflows originate from more innovative establishments
- Inventors experience more wage increase when changing jobs relative to general workers

Quantitative Analysis

- Inventor labor market friction $\uparrow \Rightarrow$ economic growth rate $\downarrow$
- Subsidies to high productivity firms $\Rightarrow$
  - Aggregate output $\downarrow$ in the short run
  - Aggregate output $\uparrow$ in the long run

Literature

- Knowledge diffusion and growth
  - Lucas and Moll (2014); Akcigit et. al. (2018); Buera and Oberfield (2020); Hopenhayn and Shi (2020); Benhabib, Perla, and Tonetti (2021); Prato (2022)
  - Inventor mobility b/w firms $\rightarrow$ knowledge diffusion
  - Match with data on inventor mobility b/w firms
- Inventor mobility and knowledge diffusion (management)
  - Almeida and Kogut (1999); Song, Almeida, and Wu (2003); Rosenkopf and Almeida (2003); Singh and Agrawal (2011)
  - Incorporate insights into growth model
  - Comparison with general workers
- On-the-job search and firm dynamics
  - Schaal (2017); Elsby and Gottfries (2021); Bilal, Engbom, Mongey, and Violante (2022)
  - Incorporate recent theoretical development to make model tractable

Inventors and Firms

- Continuous time
- Inventors are ex-ante homogeneous
- Firms are heterogeneous over
  - detrended productivity / knowledge $z \in (0, \bar{z}]$
  - the N of inventors $n \in \mathbb{R}^+$

Matching Technology

- Posting v vacancies costs $c(v)Z$
    - $c(v)$: increasing and convex in $v \in \mathbb{R}^+$
    - Z: average productivity
- A vacancy randomly matches an inventor in other firms at a rate A

Firms' Productivity Dynamics

- **In-house R&D**: Productivity z increases by $\gamma(n)z$
  - $\gamma'(n) > 0$
- **Knowledge diffusion**: When firm z poaches an inventor from firm z', productivity z increases by $\alpha(z'/z)Z$
  - $\alpha'(z'/z) > 0$
- **Leapfrog** to the technology frontier $\overline{z}$ with a rate η (Benhabib et al. 2021)

Household

- Consists of n individuals
- Each supplies inelastically one unit of inventor
- Full insurance within the family

$$\int_0^\infty e^{-\rho t} \log C(t) dt$$

$$\dot{\mathcal{A}}(t) = r(t)\mathcal{A}(t) + w(t)\mathrm{n} - C(t)$$

  - $\mathcal{A}(t)$: mutual fund that owns all firms
  - $w(t)$: average wage

Contractual Environment

- Bertrand competition when matching
  - Poaching firm makes take-leave constant wage offer
  - Targeted firm makes take-leave constant wage offer
  - Inventor decides
- Privately efficient vacancy posting (Bilal et al. 2022)
  - Firms post the number of vacancies that maximize the sum of firm's and its inventors' values.

Joint Value

- Under the contractual environment, the firm and its incumbent inventors maximize their joint value Ω
- State space: (1) firm's productivity z and (2) the N of inventors n
- Independent of the wage distributions within firms
- Allocations are obtained from $\Omega(z, n)$

Which Firms Learn from Which Firms?

- Firm (z,n) can poach inventors from firm (z',n') if

$$\underbrace{\Omega_n(z,n)}_{\text{Marginal value of inventors due to in-house R\&D}} + \underbrace{\alpha(z'/z)Z\Omega_z(z,n)}_{\text{Marginal value of inventors due to knowledge diffusion}} > \Omega_n(z',n')$$

Hamilton-Jacobi-Bellman Equation

$$\underbrace{\rho\Omega(z,n)}_{\text{Required return}} = \max_{v\geq 0} \underbrace{z}_{\text{Production}} - \underbrace{c(v)Z}_{\text{Hiring cost}}$$
$$+ \underbrace{Av\int\left[\Omega_n(z,n)+\alpha(z'/z)Z\Omega_z(z,n)-\Omega_n(z',n')\right]^+ dF_n(z',n')}_{\text{Poaching hire}}$$
$$+ \underbrace{[\gamma(n)-g]\,z\Omega_z(z,n)}_{\text{In-house R\&D} - \text{Obsolescence}} + \underbrace{\eta\left[\Omega(\bar{z},n)-\Omega(z,n)\right]}_{\text{Leapfrog}}$$

- g: economic growth rate
- F_n: inventor-weighted firm distribution

Firm-Level Productivity Drift

$$\mu_z(z,n) = \underbrace{\gamma(n)z}_{\text{In-house R\&D}}$$
$$+ \underbrace{Av(z,n)Z\int \mathbb{I}_P(z,n,z',n')\alpha(z'/z)dF_n(z',n')}_{\text{Knowledge diffusion}}$$
$$- \underbrace{gz}_{\text{Obsolescence}}$$

- $\mathbb{I}_P(z,n,z',n')$: indicator function that takes 1 if the poach successes
- In addition, we need to take into account leapfrog

Growth Rate on BGP

- Focus on a BGP where the average productivity grows at a constant rate g and the detrended firm distribution $f(z,n)$ is stationary
- Productivity growth rate of the technology frontier is

$$\bar{g} = \max_{n \in \{n | f(\bar{z},n) > 0\}} \underbrace{\gamma(n)}_{\text{In-house R\&D}} \underbrace{+ Av(\bar{z},n)\frac{Z}{\bar{z}} \int \mathbb{I}_P(\bar{z},n,z',n')\alpha(z'/\bar{z})dF_n(z',n')}_{\text{knowledge diffusion}}$$

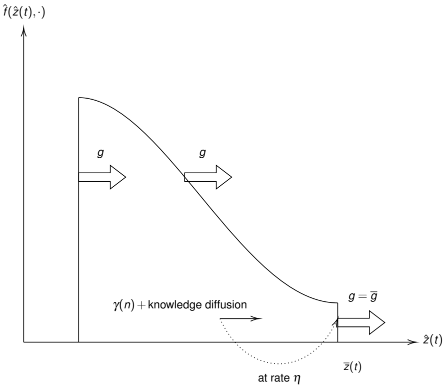
$\simeq \gamma(\bar{n})$ where $\bar{n}$ is the largest inventor size among frontier firms

- Every percentile of productivity distribution grows at the same rate $\Rightarrow$

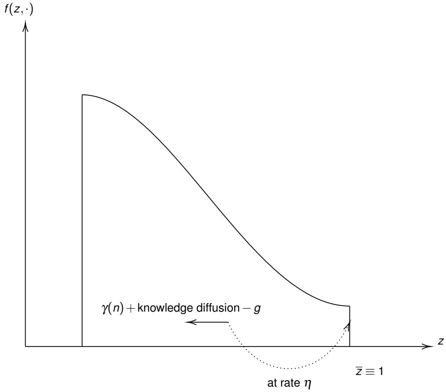
$$g = \bar{g} \simeq \gamma(\bar{n})$$

Original and Detrended Marginal Distribution

(a) Original



(b) Detrended



INV-BIO Data

- **German linked inventor biography data (INV-BIO)**
  - Inventors' patent information (European Patent Office)
    + Employer-employee match data (Germany)
  - 1980–2014
  - 152,350 inventors who have patents during 1998–2014
  - 643,856 patents

Inventor Flows across Establishments: Rank by Citation

Share of job flows (%)		Destination establishment by citation rank					
		$\leq$50%	50-60	60-70	70-80	80-90	90-100
	$\leq$50%	2.3	0.2	0.3	0.4	0.7	3.6
Origin	50-60	1.7	0.2	0.2	0.3	0.5	2.5
establishment	60-70	1.9	0.2	0.3	0.3	0.6	3.0
by citation rank	70-80	2.2	0.2	0.2	0.4	0.7	3.5
	80-90	3.5	0.4	0.5	0.6	1.2	5.9
	90-100	16.0	1.6	1.9	2.8	5.4	34.2

- $\text{citations}_e = \sum_i \text{citations}_i \times \frac{n_{ie}}{n_i}$
  - e: establishment
  - i : patent
- Higher $\rightarrow$ Lower: 39.1 $>$ Lower $\rightarrow$ Higher: 22.7
- Comparison with general workers

Inventor Job Flows and Knowledge Diffusion

$$\log z_{et+j} - \log z_{et} = \beta_1 \text{H-Share}_{et} + \beta_2 X_{et} + \alpha_e + \alpha_t + \varepsilon_{et}$$

- z_{et}: patent citations at establishment e in year t
  - 3–5 years forward citation
  - backward 3-year moving average
- H-Share_{et}: inventor inflows from higher z_{et} / total inventor inflows to e
- X_{et}: total inventor inflows to e, $\log(\text{N of inventors})$, $\log(\text{N of employee})$, mean wage of employee, z_{et}
- α_e, α_t: establishment & year FE

$z \uparrow$ When Inventors Come from High

	$\log z_{et+j} - \log z_{et}$				
	$j = 3$	$j = 4$	$j = 5$	$j = 3$	$j = 3$
H-Share$_{et}$ (%)	.0022***	.0028***	.0027***	.0024***	.0024***
	(.0004)	(.0004)	(.0004)	(.0003)	(.0003)
Control	√	√	√	√	√
Fixed Effects	√	√	√	√	√
Citation	3y fwd	3y fwd	3y fwd	4y fwd	5y fwd
N	24,625	22,270	19,982	25,791	26,451

Notes: SEs clustered by year and establishments are reported in parentheses. * $p < 0.1$, **$p < 0.05$, *** $p < 0.01$.

- The results are robust when we use regional patent citation rank as IV IV

SIAB Data: Comparison with General Workers

- **Sample of Integrated Labour Market Biographies (SIAB)**
  - linked employer-employee data in Germany
  - 2% random sample of workers
  - 1980–2019
  - 3,322,316 individuals

How Do Inventors' Wages Change When Changing Jobs?

$$\log w_{it} - \log w_{it-1} = \beta_1 I_{it} + \beta_2 D_{it} + \beta_3 D_{it} I_{it} + \beta_4 X_{it} + \alpha_e + \alpha_t + \varepsilon_{it}$$

- w_{it}: the wage of job changer *i* in year *t*
- I_{it}: inventor dummy
- $D_{it} = 1$ if moving to a less productive establishment
  - Use (1) size or (2) mean wage as proxy for productivity
- X_{it}: age, the square of age, gender, and education
- α_e, α_t: Destination establishment & year FE

Inventors' Wages Increase More When Changing Jobs

	$\Delta \log w_{it}$	
I_{it}	.017***	.021***
	(.005)	(.004)
D_{it}	$-$.078***	$-$.084***
	(.006)	(.005)
$D_{it} \times I_{it}$	.016***	$-$.002
	(.006)	(.006)
Control	$\surd$	$\surd$
Fixed Effects	$\surd$	$\surd$
Measure for D_{it}	Size	Mean wage
N	859,888	859,861

Notes: SEs clustered by year and establishments are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Implication of Empirical Findings

- We find
  - Patent productivity grows faster when a larger proportion of inventors originate from more innovative establishments
  - Inventors experience more wage increase when changing jobs relative to general workers
- These findings imply
  - inventors transfer knowledge, especially from high to low
  - firms compensate for knowledge diffusion
- Our model has these features

Functional Forms

- In-house R&D rate function: $\gamma(n,i) = \overline{\gamma}_i n^{\delta},\ i \in \{h,l\}\,,\ \overline{\gamma}_h > \overline{\gamma}_l$
  - Assume firm's innovative ability i follows two-state Markov process
  - $h \to l$ at a rate λ_h, $l \to h$ at a rate λ_l
  - The state variables are now (z,n,i)
- Knowledge diffusion rate function: $\alpha(z'/z) = \overline{\alpha}\,(z'/z)^{\beta}$
- Vacancy cost function: $c(v) = \frac{\overline{c}}{\phi+1} v^{\phi+1}$

Calibration: Externally Set or Directly Matched to Data

Parameter	Description	Value	Moment
ρ	Discount Rate	0.0041	5% annual real interest rate
ϕ	Vacancy Cost Elasticity	3.45	Bilal et al. (2022)
$\overline{z}$	Frontier Productivity	1	Normalization
m	Measure of Firms	1	Normalization
$\overline{c}$	Vacancy Cost Coefficient	100	Normalization
$\overline{\gamma}_l$	l-type R&D Coefficient	0	Normalization
n	Measure of Inventors	5	Ave. N of inventors per estab.
λ_l	$h \to l$	0.01	
λ_h	$l \to h$	0.02	

- λ_l and λ_h match estimation of 2 state Markov transition matrix for the change in patent productivity Δz_{et} of establishments with z_{et} in top 10%. Establishments with $\Delta z_{et} > 0$ (< 0) are labeled h (l).

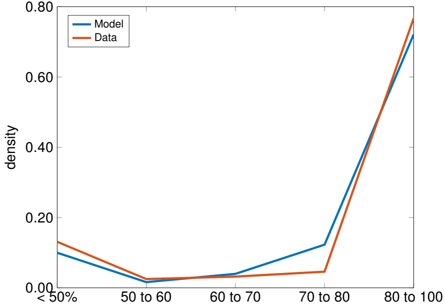
Calibration: Internally Estimated

Parameter	Description	Value
β	Knowledge Diffusion Curvature	0.33
$\overline{\alpha}$	Knowledge Diffusion Rate	0.0012
δ	R&D Curvature	0.25
$\overline{\gamma}_h$	*h*-type R&D Rate	0.0006
η	Leapfrog	0.0001
A	Matching Efficiency	0.26

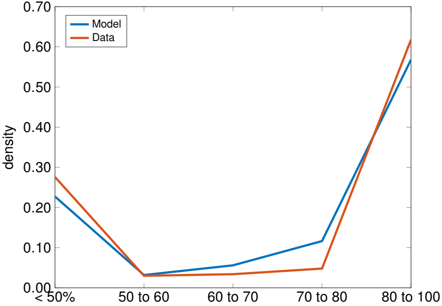
Moments	Data	Model
TFP Growth Rate (%, monthly)	0.16	0.13
Job to Job Transition Rate of Inventors (%, monthly)	1.17	1.13
Distribution of Inventors by Establishments' Patent Citation Rank	Next Slide	
Inventor Job Inflows by Establishments' Patent Citation Rank	Next Slide	

Moments: Inventor Distributions by Productivity Rank

(a) Inventor Distribution by Productivity Rank

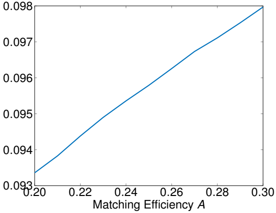


(b) Inventor Inflow by Productivity Rank

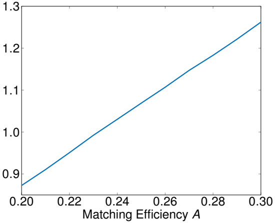


Comparative Statics: Matching Efficiency

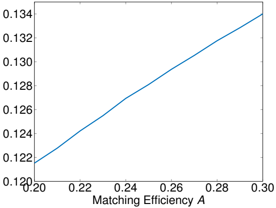
(a) Aggregate Vacancies



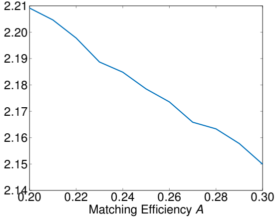
(b) EE Rate (%)



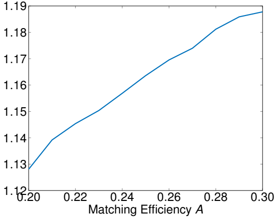
(c) Growth Rate (%)



(d) St.d. of $\log z$



(e) St.d. of $\log n$

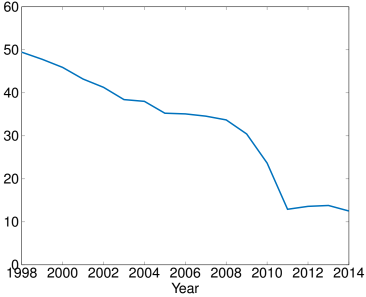


Matching Efficiency $A \uparrow \rightarrow$ Economic Growth Rate $g \uparrow$

- Matching efficiency $A \uparrow$
- Inventor job flows $\uparrow$
- Knowledge diffusion $\uparrow$
- Productivity dispersion $\downarrow$
- High z firms (mainly grow by in-house R&D) hire more inventors relative to low z firms (mainly grow by knowledge diffusion)
- Innovation at technology frontier $\uparrow$
- Economic growth rate $g \uparrow$

Inventor Job Flow Decline and Secular Stagnation

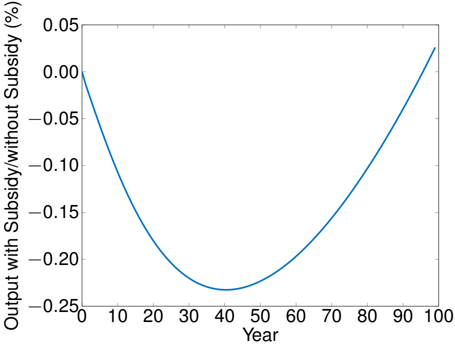
Inventor Job Flow Rate in Germany (%)



- Akcigit and Goldschlag (2023) also document that inventor mobility has decreased since early 2000s in the US
- The model indicates inventor job flow rate ↓ is a source of TFP growth ↓ observed in recent decades

Transition Dynamics of Z: Subsidy to High z Firms

- Subsidize 10% of production for the top half of the productivity distribution (inventor weighted)



1. Inventor job flow from high z to low z firms $\downarrow$: dominate in short run
2. Inventor stock at high z firms $\uparrow$: dominate in long run

Conclusions

- Endogenous growth model with frictional labor market for inventors
  - inventors engage in in-house R&D
  - poaching firms learn from poached firms
- Administrative panel dataset on German inventors suggests
  - inventors transfer knowledge, especially from high to low
  - firms compensate for knowledge diffusion
- Calibrated model using German data implies
  - labor market friction $\uparrow \Rightarrow$ economic growth rate $\downarrow$
  - subsidies to high productivity firms $\Rightarrow$ aggregate productivity $\downarrow$ in short run / $\uparrow$ in long run

Firm-Level Change in the N of Inventors

$$\mu_n(z,n) = \underbrace{Av(z,n)\int \mathbb{I}_P(z,n,z',n')dF_n(z',n')}_{\text{Poaching hire}}$$
$$\underbrace{-A\mathrm{v}\frac{n}{\mathrm{n}}\int \mathbb{I}_P(z',n',z,n)dF_v(z',n')}_{\text{Poached by other firms}}$$

- v: total vacancies
- n: total inventors
- F_v: vacancy-weighted firm distribution

Kolmogorov Forward Equation

$$0 = \underbrace{-\frac{\partial}{\partial n}(\mu_n(z,n)f(z,n))}_{\text{N of inventor growth}} \underbrace{-\frac{\partial}{\partial z}(\mu_z(z,n)f(z,n))}_{\text{Productivity growth}}$$
$$\underbrace{-\eta f(z,n) + \eta \int_0^{\overline{z}} f(z,n)dz\Delta(\overline{z})}_{\text{Leapfrog}}$$

- $\Delta(\overline{z})$: Dirac delta function

Available Variables in INV-BIO

- Inventors' biography
  - age, education, place, nationality, ...
- Employment characteristics
  - wage, occupation, unemployment status, ...
- Establishment characteristics
  - industry, age(1975-), the N of employees, mean wage, place, ...
- Patent characteristics
  - date, citations, technology area, ...

Summary Statistics: INV-BIO

Establishment level variables	Mean	S.D.	*N* of est. (thus.)
N of inventors (n_{et})	4.9	18.5	119
N of employees	688.9	2150.6	119
Mean daily wage, Euro	121.6	55.5	119
N of three-year forward citations for patents (per inventor, three-year backward average, z_{et})	11.3	69.2	119
Share of inventors moving from higher productivity est. (H-Share$_{et}$), %	61.2	49.5	119
Total inventor inflows	1.67	5.30	119

Summary Statistics: SIAB

Worker level variables	Mean	S.D.	*N* of workers (thus.)
Dummy for moving to less productive est. (D_{it})			
based on est. size	0.50	-	4,669
based on mean wage	0.52	-	4,583
Dummy for the identified inventors (I_{it})	0.10	-	5,691
Daily Wage, Euro	44.4	42.1	5,691
Age	33.7	12.9	5,691
Share of Women, %	47.3	-	5,691

Distribution of Inventors by Patent Citation Rank

Percentile rank	$\leq$50%	50-60	60-70	70-80	80-90	90-100
Share of Inventors (%)	13.1	2.5	3.2	4.6	8.9	67.8

Identified Inventors in SIAB and Inventors in INV-BIO

Summary statistics (1980 - 2014)		SIAB Workers	SIAB Identified inventors	INV-BIO Inventors
Daily wage, Euro	Mean	59.0	78.9	156.2
	S.D.	47.2	52.1	30.0
Age	Mean	38.7	38.4	42.4
	S.D.	12.9	12.4	9.0
Females, %		45.2	14.8	5.7
N of obs., thousand		21,344	2,871	420

Notes: Identified inventors in SIAB are workers who work in the following four occupations: "research and development", "machine-building and operations", "mathematics, biology, and physics", and "mechatronics, energy, and electronics."

Regional Ranks of Innovativeness as IV

- Regional Rank$_{et}$: Regional patent citation rank of estab e in year t
- Instrument relevance: $\text{Cov}[\text{Regional Rank}_{et-1} \cdot \text{H-Share}_{et}] \neq 0$
  - Lower productivity ranks in the local labor market $\Rightarrow$ More poaching from higher productivity estab
- Instrument exogeneity: $\mathbb{E}[\varepsilon_{et} | \text{Regional Rank}_{et-1}, X_{et}, \text{FE}] = 0$
  - Given the control variables X_{et}, Regional Rank$_{et-1}$ does not directly affect the future innovation outcomes

$z\uparrow$ When Inventors Come From High: IV

	$\log z_{et+j} - \log z_{et}$				
	$j=3$	$j=4$	$j=5$	$j=3$	$j=3$
H-Share$_{et}$ (%)	.092***	.101***	.103***	.084***	.088***
	(.007)	(.007)	(.009)	(.005)	(.006)
Control	√	√	√	√	√
Fixed Effects	√	√	√	√	√
Citation	3y fwd	3y fwd	3y fwd	4y fwd	5y fwd
First Stage IV					
Regional Rank$_{et-1}$	24.4***	22.7***	22.8***	30.0***	29.3***
	(1.7)	(1.5)	(1.8)	(1.7)	(1.7)
N	22,213	20,052	17,996	23,137	23,609
F statistic	204.8	232.6	155.2	302.7	286.2

Notes: SEs clustered by year and establishments are reported in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

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Comparison with General Workers Using SIAB Data

- In INV-BIO, most inventors belong to following four occupations:
    - "research and development" (20.2%)
    - "machine-building and operations" (19.8%)
    - "mathematics, biology, and physics" (19.1%)
    - "mechatronics, energy, and electronics" (18.8%)
- In the next analysis, we regard workers who belong to one of the four occupations as inventors

Inventor Mobility Relative to General Workers

- Do inventors tend to move from high to low relative to general workers?

$$P\left(D_{it}=1 \mid I_{it}, X_{it}\right)=\Phi\left(\beta_0+\beta_1 I_{it}+\beta_2 X_{it}\right)$$

- i: job changer without unemployment spell
- t: 1980–2019
- X_{it}: age, a square of age, gender, and education

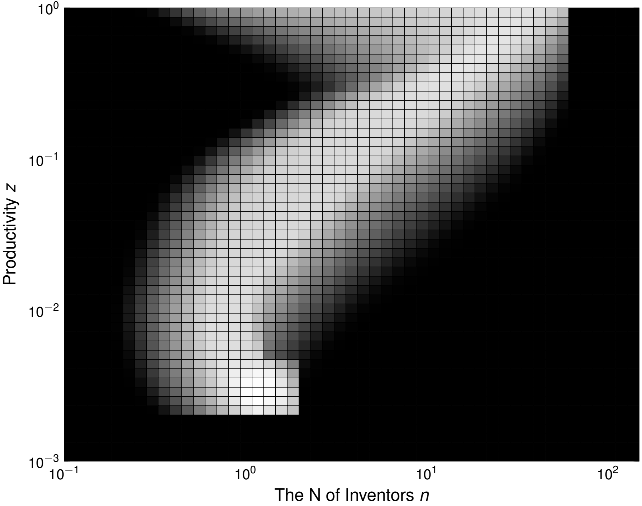
Inventors Tend to Move from High to Low

	$P(D_{it}=1)=1$			
	Whole sample		Wage↑	
I_{it}	.077***	.036***	.052***	.012***
	(.004)	(.004)	(.004)	(.004)
Control	$\surd$	$\surd$	$\surd$	$\surd$
Measure for D_{it}	Size	Mean Wage	Size	Mean Wage
N	3,572,567	3,533,344	2,082,939	2,060,714

Notes: SEs clustered by year and establishments are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

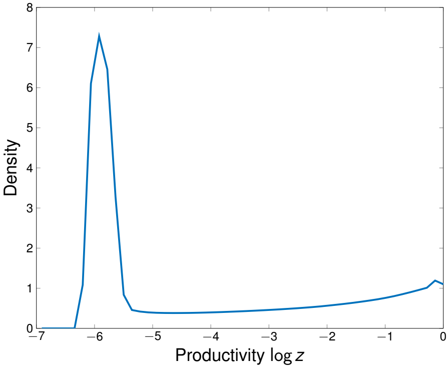
- back

Density of Firms $\log f(z, n)$

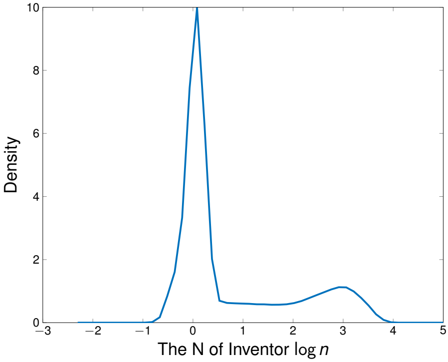


Marginal Density of Firms

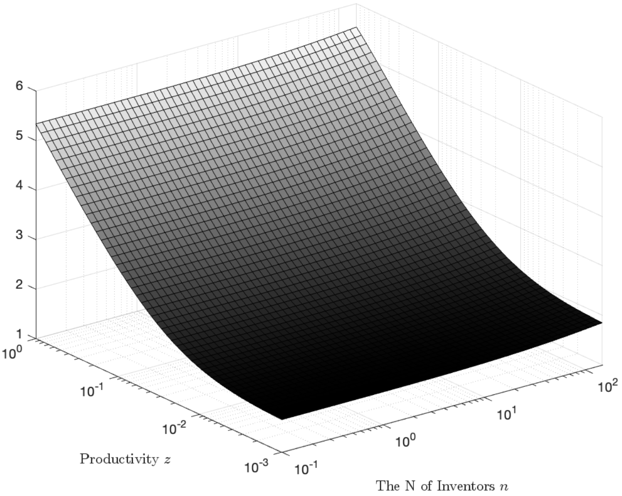
(a) Marginal Density of Firm Productivity



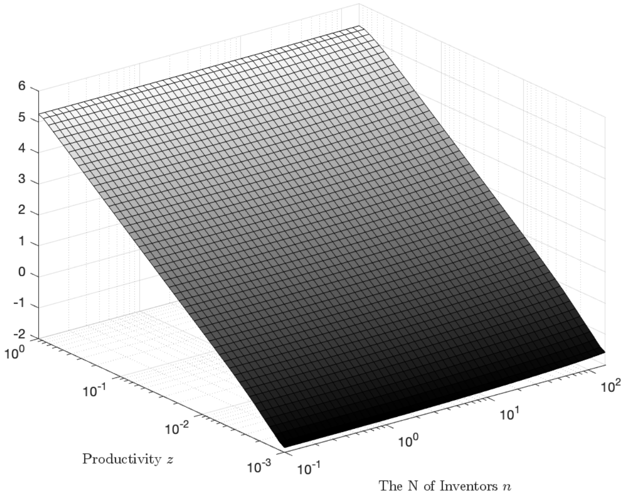
(b) Marignal Density of the N of Inventor



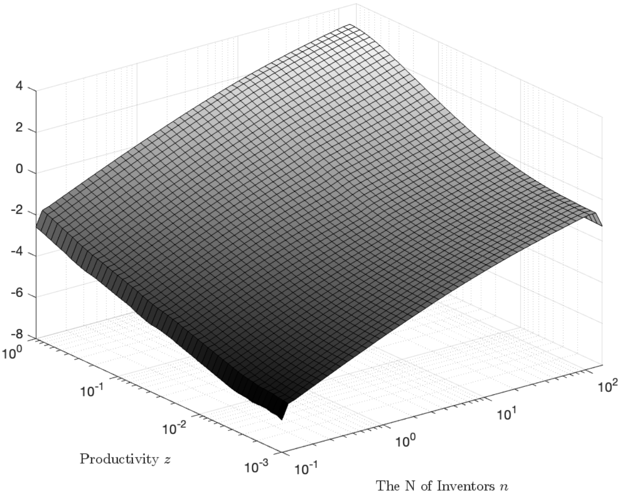
Value Function $\log \Omega(z, n)$



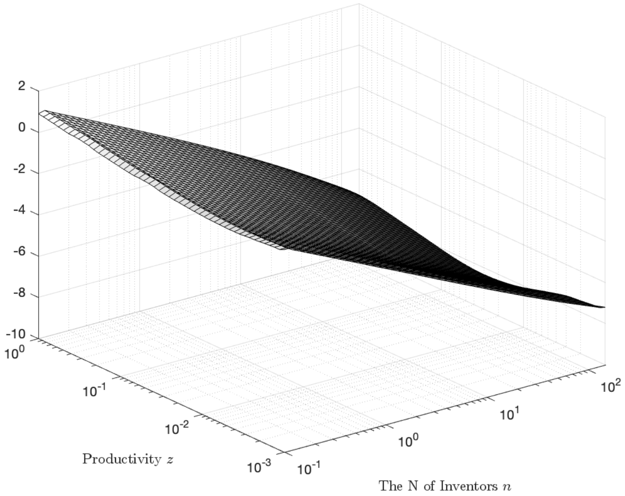
Marginal Value of Productivity $\log \Omega_z(z, n)$



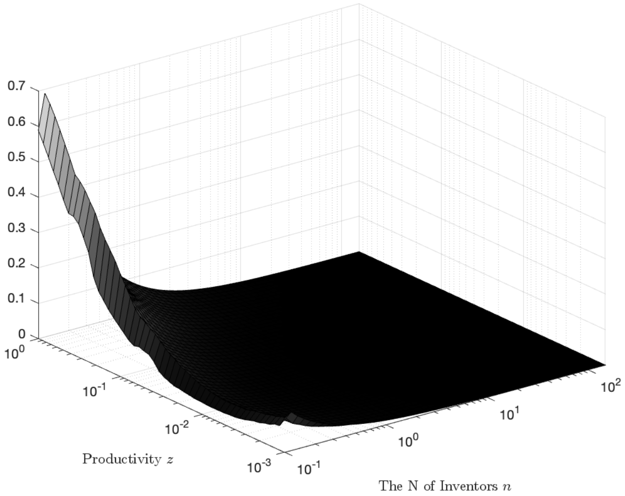
Marginal Value of Inventor $\log \Omega_n(z, n)$



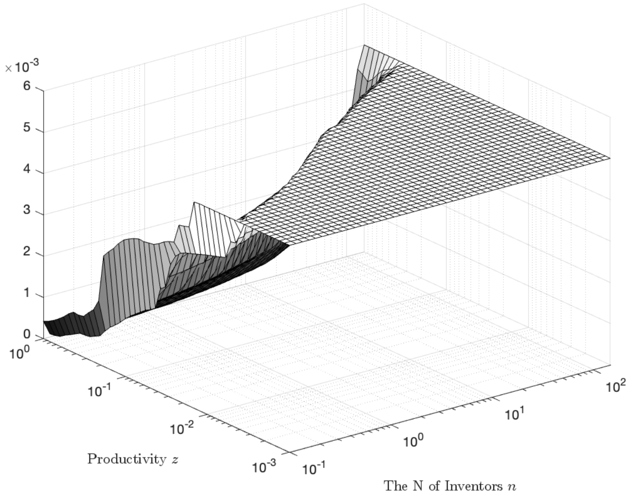
Vacancy Posting Rate $\log\left(v(z,n)/n\right)$



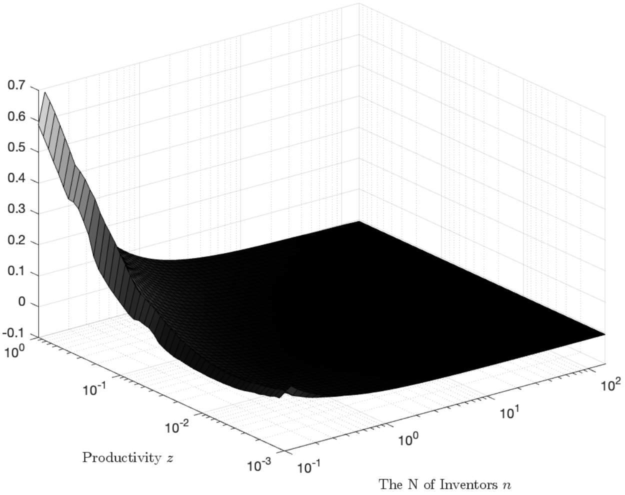
Hiring Rate


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10^0
10^{-1}
10^{-2}
10^{-3}
Productivity z
10^{-1}
10^0
10^1
10^2
The N of Inventors n

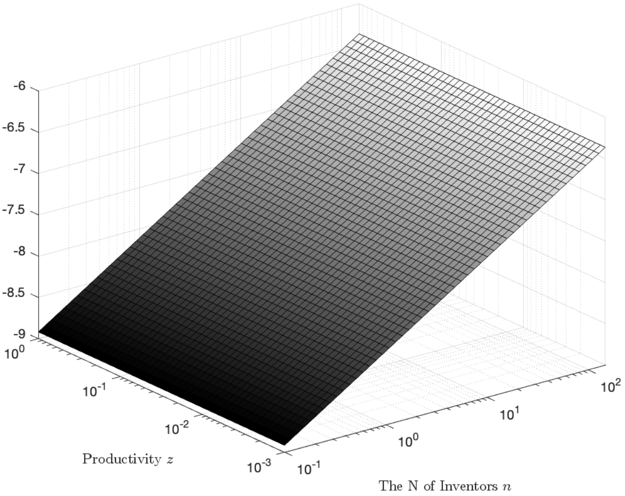
Separation Rate



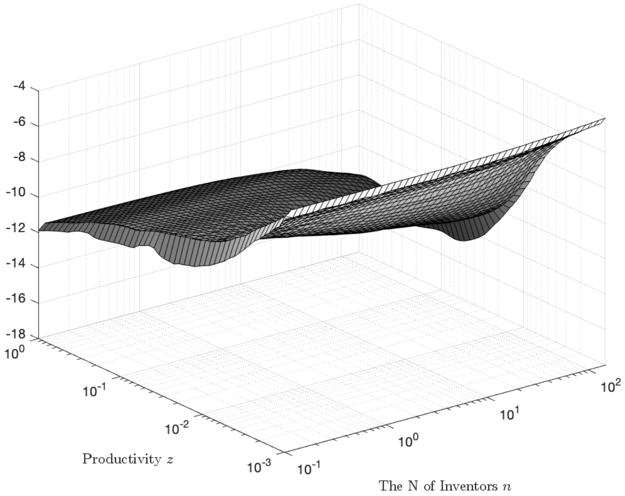
Inventor Growth Rate $\frac{\dot{n}}{n}(z, n)$



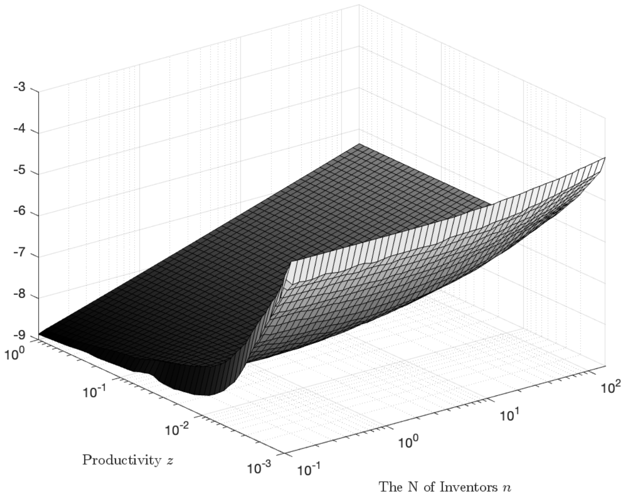
R&D Growth Rate (log)



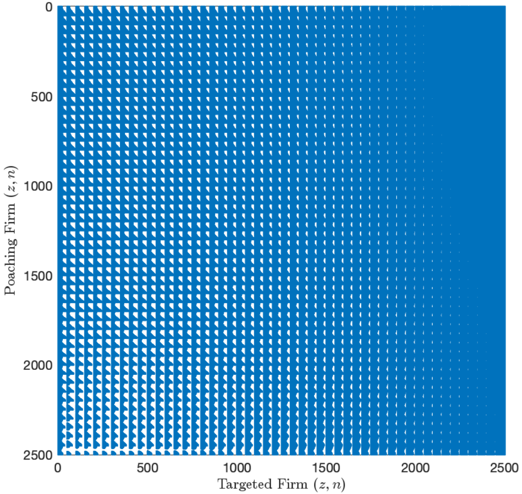
Knowledge Diffusion Growth Rate (log)



Productivity Growth Rate $\log\left(\frac{\dot{z}}{z}(z,n)\right)$

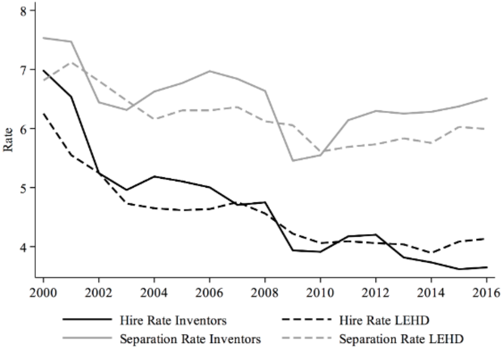


Poaching Success Indicator $\mathbb{I}_P(z, n, h, z', n', h)$



Inventor Job Flow in the US (Akcigit and Goldschlag)

FIGURE 11: INVENTOR HIRE AND SEPARATION RATES



Source: Inventor Employment History
Notes: Figure shows Hire and Separation (QWI definition of stable hires and separations) for inventors and a 1% sample of the LEHD for comparison. The 1% LEHD sample is weighted to reflect the time varying industry composition of the inventor sample and thus captures the hire and separation of workers in industries in which inventors are most frequent.